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ARTICLE

Growth and development of cut sunflowers in the dry and rainy season monitored by an automated system

Crescimento e desenvolvimento do girassol de corte na estação seca e chuvosa monitorado por sistema automatizado

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Abstract
Cut sunflower (*Helianthus annuus* L.) is an important flower crop for income diversification for small producers. Semi-arid regions, such as the Southern Agreste of Pernambuco, experience an annual alternation between dry and wet seasons. This imposes challenges on the production of ornamental species, requiring species and cultivars adapted to climatic variations and tolerant to water deficit. The objective in this study was to evaluate the response of cut sunflower during the dry and the rainy seasons through an automated monitoring system, with the goal of contributing to the technological and sustainable improvement of regional floriculture. Field experiments were conducted with the sunflower hybrid Vincent's Choice, during the dry season (from September to December 2024) and during the rainy season (from March to August 2025). Pre-planting organic and chemical and fertilization was carried out in the soil, and environmental conditions were monitored using DHT22 sensors integrated with solar power modules, cloud storage, and a mobile app developed on the Thunkable platform. Growth, development, physiological, gas exchanges, and chlorophyll index were evaluated. During the dry season, plants had greater earliness, leaf area and stem and capitulum diameter, and lower height and number of leaves compared to the rainy season. The ESP32-CAM integrated with a mobile app, named GirassolCam, emerges as a promising tool for monitoring cut sunflower development and intelligent crop management, especially in semi-arid regions, contributing to more sustainable and efficient agronomic management practices in the flower production system.
Keywords: *Helianthus annuus*, agriculture 4.0, agricultural automation, seasonality, sustainable floriculture.

Resumo
O girassol cortado (*Helianthus annuus* L.) é uma cultura importante para diversificação de renda para pequenos produtores. Regiões semi-áridas como o Agreste Meridional de Pernambuco possui alternância anual entre uma estação seca e uma estação chuvosa impõe desafios à produção de espécies ornamentais, exigindo espécies e cultivares adaptados às variações climáticas e tolerantes ao déficit hídrico. O objetivo deste estudo foi avaliar a resposta do girassol de corte durante as estações seca e chuvosa por meio de um sistema automatizado de monitoramento, com o objetivo de contribuir para a melhoria tecnológica e sustentável da floricultura regional. Experimentos de campo foram realizados com o híbrido de girassol Vincent's Choice, durante a estação seca (de setembro a dezembro de 2024) e durante a estação chuvosa (de março a agosto de 2025). O pré-plantio orgânico, químico e a fertilização foram realizados no solo, e as condições ambientais foram monitoradas usando sensores DHT22 integrados a módulos de energia solar, armazenamento em nuvem e um aplicativo móvel desenvolvido na plataforma Trunkable. Foram avaliados crescimento, desenvolvimento, fisiologia, trocas gasosas e índice de clorofila. Durante a estação seca, as plantas apresentavam maior precocidade, área foliar, diâmetro do caule e do capítulo, além de menor altura e número de folhas em comparação com a estação chuvosa. O ESP32-CAM integrado a um aplicativo móvel chamado GirassolCam, surge como uma ferramenta promissora para monitorar o desenvolvimento do girassol de corte e o manejo inteligente das culturas, especialmente em regiões semiáridas, contribuindo para práticas de manejo agronômico mais sustentáveis e eficientes no sistema de produção de flores.
Palavras-chave: *Helianthus annuus*, agricultura 4.0, automação agrícola, sazonalidade, floricultura sustentável.

Introduction

The cultivation of cut sunflowers (*Helianthus annuus* L.) has stood out as a promising source of crop diversification and income for small producers in Brazil, due to its high profitability on small areas, fast financial return, and contribution to keep families in rural areas (Alves et al., 2025; Fonseca et al., 2026). The location of production areas can influence logistical efficiency and the quality of marketed flower stems. These are the pillars of the "Flowers for All Project" (Projeto Flores para Todos), the largest inclusive project in Brazilian floriculture, which started in 2018 nationwide and in December 2025 completed 8 years, reaching 472 small family farming households in 21 states across all five regions of Brazil (Uhlmann et al., 2019; Streck and Uhlmann, 2021; Fonseca et al., 2024). Cut sunflower is one of the cut flowers species introduced in the "Flowers for All Project" in 2020 (Tomiozzo et al., 2024; Alves et al., 2025).

In some regions with a transitional region between the humid climate of the *Zona da Mata* near the coast of the Atlantic Ocean and the semi-arid hinterland, agricultural production is characterized by pronounced seasonality due to a dry and rainy season on an annual basis. The alternation between dry and rainy season poses challenges for the production of ornamental species, especially those with high commercial value, such as cut sunflowers. Despite the region productive potential, studies linking the morphophysiological response of sunflowers to local climate seasonal variations are still scarce, which makes it difficult to define and propose an ideal cultivation and management periods.

The incorporation of digital technologies in agriculture, characteristic of the so-called Agriculture 4.0, has been providing new opportunities for the monitoring and management of ornamental crops. Among the emerging tools, the ESP32-CAM microcontroller stands out as a low-cost and highly versatile device capable of integrating environmental sensors, connectivity modules, and cameras for real-time data acquisition (Raiaan et al., 2023). This type of system is compatible with the Internet of Things (IoT), allowing remote monitoring of temperature, humidity, and light parameters, in addition to supporting the automation of agricultural processes (Santos et al., 2021).

Recent studies reinforce the importance and potential for the development of these technologies. Soetedjo & Hendriarianti (2023) developed an IoT-based SCADA system for continuous and remote real-time monitoring of plants, Faysal and Mohammed (2021) applied the ESP32-CAM in intelligent irrigation systems. However, there is a lack of research integrating the use of these technologies with the study of

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seasonality in cut flowers. Therefore, the objective in this study was to evaluate the response of cut sunflower during the dry and the rainy seasons in the *Agreste* region of Pernambuco, through an automated monitoring system, with the goal of contributing to the technological and sustainable improvement of regional floriculture.

Materials and Methods

The experiment was carried out under field conditions in a semi-arid tropical environment, with well-defined dry and rainy seasons. (8°53'S, 36°29'W, 822 m above sea level), using seeds of the Vincent's Choice sunflower hybrid. The experimental area is characterized by annual precipitation ranging from 291 mm to 1043.04 mm, a rainfall index below 800 mm, and a drought risk exceeding 60% (APAC, 2025). The study was carried out in two periods with distinct climatic characteristics: during the dry season, from September to December 2024, and during the rainy season, from March to August 2025.

The sowing was carried out in trays containing commercial substrate of the Carolina Soil type. The sowing date during the dry season was on 29/10/2024 and during the rainy season was on 28/04/2025. Nine days after emergence, the seedlings were transplanted to a bed 1 m in width and 3.15 m in length. Plants were arranged in four rows, with 20 cm spacing between rows and 12.5 cm between plants, totaling 100 plants/experimental units per bed and a density of 32 plants m^{-2}, according to the standard PhenoGlad protocol and used nationwide in the "Flowers for All Project" (Tomiozzo et al., 2024; Alves et al., 2025).

Pre-planting fertilization in the bed was with 8.5 kg of well-rotted cattle manure into the soil, soil acidity correction with calcitic limestone was performed according to soil analysis requirements, up to 500 g m^{-2}, and chemical fertilization with NPK 05-20-20 at a rate of 50 g m^{-2}. Seven days after seedlings transplanting, topdressing fertilization was carried out with urea 46-00-00 at a rate of 50 g m^{-2}. Meteorological data were collected from a station located in close proximity to the experimental area within the university campus. Daily minimum and maximum temperature and relative humidity were obtained from station A322 of the National Institute of Meteorology (INMET, 2025), while accumulated daily precipitation data were provided by the Pernambuco Water and Climate Agency (*Agência Pernambucana de Águas e Clima* - APAC), meteorological unit 19, throughout the entire developmental cycle.

The experiment was conducted in a completely randomized design with 100 plants of the Vincent's Choice cut sunflower hybrid. Ten plants were randomly selected and tagged in the two central rows of the bed and used for weekly measurements of growth and development variables: the accumulated number of leaves (NL), plant height (PH), measurement from the stem to the apex of the capitulum using a ruler in centimeters, stem diameter (SD), and capitulum diameter (HD) using a digital caliper. Leaf area (LA) for leaves larger than 2 cm was estimated by multiplying length, width, and a correction factor of 0.733. Furthermore, the developmental stages R1 (visible bud), R4 (visible petal color), R5 (petals at 90º from the capitulum disc), and R5.1 (10% of tubular flowers open in the capitulum) (Schneiter and Miller, 1981), were also measured on the 10 tagged plants by daily observation. The date of the developmental stage was assumed when 50% of the tagged plants achieved each developmental stage.

Physiological variables on the tagged plants were assessed weekly during the developmental cycle, including chlorophyll index a, b, and total (a + b), obtained with a portable chlorophyll meter (Falker®, Brazil) in the early morning. Gas exchange (net photosynthesis, stomatal conductance, transpiration, internal CO_2 concentration, instantaneous water use efficiency, instantaneous carboxylation efficiency, and leaf temperature) were determined weekly between 10:00 a.m. and 11:30 a.m., using an infrared gas analyzer (IRGA, ADC-BioScientific Ltd., Model LCPro SD) only during the dry period.

An automated monitoring system was developed for the collection of meteorological data and plant images. The equipment was based on the ESP32-CAM microcontroller, integrated with the DHT22 sensor for measuring air temperature and humidity. The system was powered by a 12 V, 20 W solar panel, with charge control carried out by the CN3791 MPPT module, responsible for optimizing the charging of lithium batteries (3.7-4.2 V) (Fig. 1).

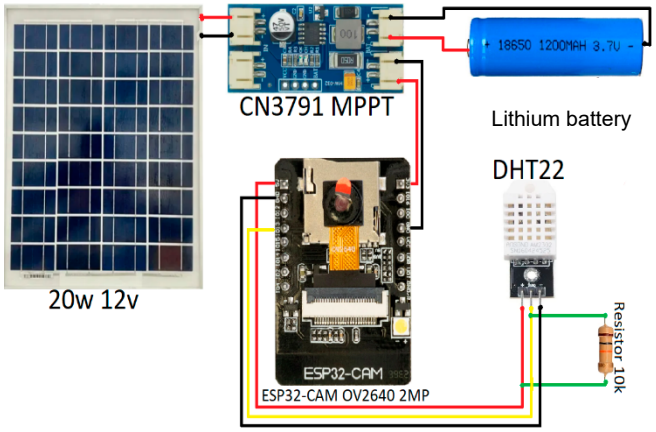

Fig. 1. Connection diagram of a compact solar system using ESP32-CAM used in the study.

The programming of the ESP32-CAM was done in C++ language, and programmed to capture images and environmental data every hour, automatically transmitting them to a REST API hosted on the server of the Suassuna Robotics Club (*Clube de Robótica Suassuna*) at the Cria Space of the Ariano Villar Suassuna State Technical School (*Espaço Cria da Escola Técnica Estadual Ariano Villar Suassuna*) in the municipality of Garanhuns - PE, in partnership with the Federal University of *Agreste* of Pernambuco (*Universidade Federal do Agreste de Pernambuco*). The mobile app was called GirassolCam, developed on the Thunkable platform, and allowed remote access to the images and recorded data, displaying temperature and humidity graphs and an automated leaf counting tool using computer vision (OpenCV).

The field growth, developmental, physiological, and gas exchange data were statistically analyzed using analysis of variance (ANOVA) based on a completely randomized design (CRD) through R software, and mean comparisons were made using Tukey test ($p < 0.05$). Pearson correlation analysis was also performed among all evaluated variables (growth, physiological, and gas exchange parameters), considering a significance level of ($p < 0.05$).

Results and Discussion

The ESP32-Cam microcontroller received all the data (image, temperature, and humidity) and then they were sent to a REST (Representational State Transfer) API, an application programming interface that follows the principles of the REST architectural style for communication between systems, usually via HTTP. That means it is an Internet of Things technology used to send, receive, and store data in the cloud. In this case, we received the raw data and monitored it through a mobile app (the GirassolCam app) that provided the interface/view with the equipment data.

The GirassolCam application was developed on the Thunkable platform, an online environment that enables the development of mobile applications without the need for advanced programming. Its interface was structured into functional modules comprising an initial access

screen with a user registration and login system, integrated with an area dedicated to data visualization. This section presents the images, temperature and relative humidity records, and monitoring graphs, which were implemented to display the minimum, average, and maximum values of these climatic variables, allowing for the visual analysis of the monitored environment (Fig. 2).

The GirassolCam app was developed with a focus on usability and ease of understanding for the user. On the home screen, the logo and buttons to access the main interface and to register a new user are displayed (Fig. 2A and B). The third screen has shortcuts for different data areas, such as images, temperature, and humidity, as well as graphs corresponding to these variables (Fig. 2C). On the fourth to sixth screens (Fig. 2D, E and F), column charts with the daily minimum, average, and maximum values of temperature and humidity are displayed, providing a clear and objective view of the environmental conditions. On the seventh screen (Fig. 2G), the automatic leaf count (using OpenCV - Open-Source Computer Vision Library) is displayed, and finally, there are album screens where the captured images are shown along with temperature, humidity, and date/time.

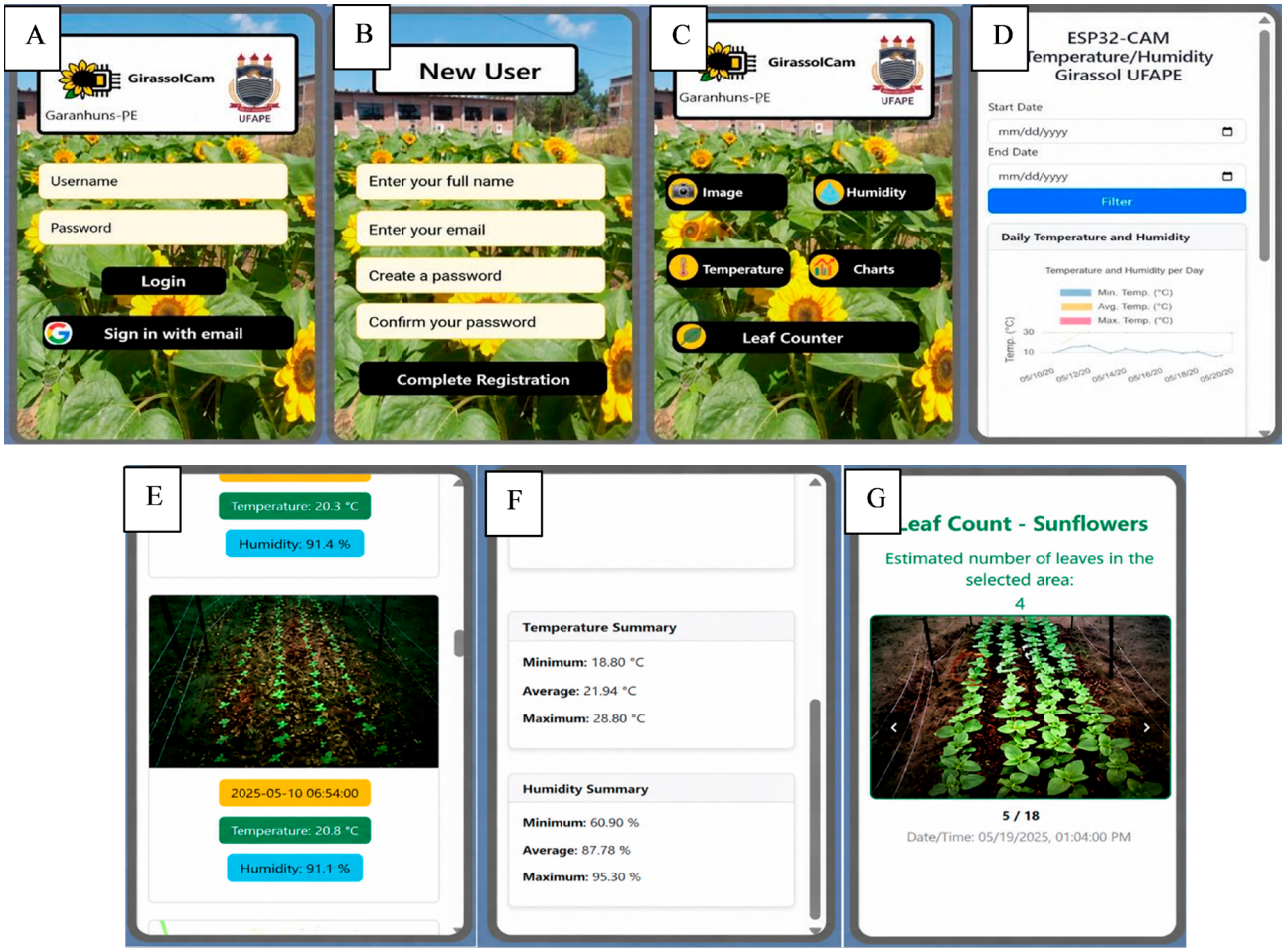

Fig. 2. Displays of the GirassolCam app developed in the study.

During the developmental cycle of cut sunflower in both seasonal periods, plants showed development and growth consistent with the cultivation standard, with leaf emergence rates and plant height in line with what is expected for the crop. The Esp32-Cam system installed in the area recorded the data, allowing for a visual monitoring of growth progress and the transition between developmental stages (Fig. 3A), facilitating decision-making of agronomic management practices. The solar-powered device also demonstrated good autonomy evidenced by the constant maintenance of battery voltage levels above the minimum required for operation, sustained solely by the solar panel, and practicality, as it can be installed in different locations in the field, requiring only a stable Wi-Fi network signal configured according to the expected standards for its connection (Fig. 3B).

Plant height and the final number of leaves showed different responses between the dry and rainy seasons at the end of the growth cycle. Plants in the rainy season were taller ($p < 0.01$), with an increase of approximately 14% in plant height compared to cultivation in the dry season (Fig. 4A). Similar results were observed for final leaf number, with a higher final number of leaves during the rainy season (Fig. 4B), indicating that increased moisture favors leaf development in cut sunflower plants. On the other hand, the dry period may have reduced turgor pressure and increased stomatal closure due to higher temperatures (Taiz et al., 2021), resulting in a lower number of leaves to conserve water during hotter periods of the cycle. These results indicate that the rainy season promotes the prolongation of vegetative development, resulting in greater plant height and a higher number of leaves at the end of the cultivation cycle. These findings are consistent with Alves et al. (2025), who also observed similar growth of cut sunflower during the same period.

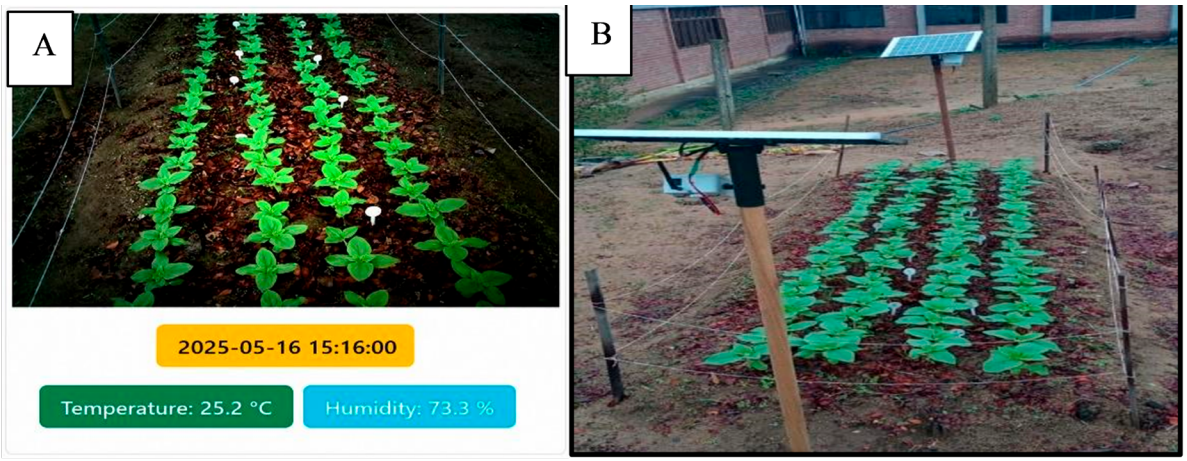

Fig. 3. (A) Records of the hybrid cut sunflower Vincent's Choice gown in the field with the GirassolCam app using the Esp32-CAM microcontroller, 18 days after sowing (DAS) and (B) solar-powered device of Esp32-CAM microcontroller installed in the field during the rainy season.

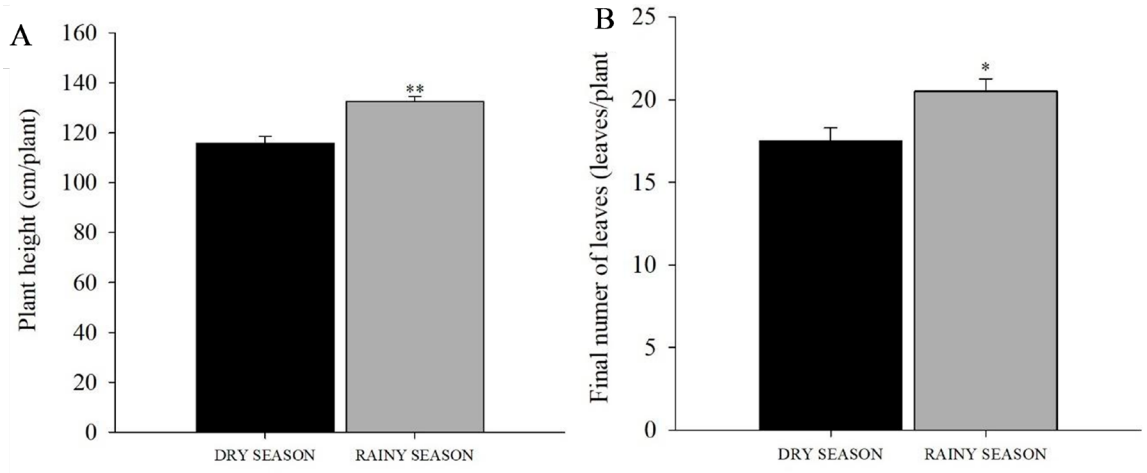

Fig. 4. (A) Plant height and (B) final number of leaves of hybrid Vincent's Choice cut sunflower plants grown in the dry season and in the rainy season at 59 days after sowing. Error bars representing one standard deviation of the mean are presented on the top of each column. Asterisks indicate significant difference at 5% (*) or 1% (**) according to the Tukey test between the dry season and the rainy season for each variable.

When comparing meteorological data during the dry season and the rainy season, the impact of thermal conditions on sunflower development becomes evident. In the dry season, the average temperatures were more stable, ranging from 22.9 ºC to 23.8 ºC, associated with an average relative humidity of 72% (Fig. 5A), favoring faster development, reaching the harvest point at 43 DAS. In contrast, it was observed that in the rainy season, development occurred more slowly, influenced by milder average temperatures with a greater thermal amplitude, ranging from 20.6 ºC to 24.5 ºC (Fig. 5B), along with higher relative humidity of 84% (ESP32-CAM), consequently delaying the development stages and prolonging the crop cycle to 59 DAS. This difference is directly linked to the physiological responses of the plants when exposed to different meteorological conditions occurring in each season, mainly temperature and its fluctuation.

The average temperature of the dry season was 23.3 ºC and of the rainy season was 22.4 ºC, meaning there was an average difference of 0.9 ºC between these two periods, while humidity showed a variation of 12%. This difference may be associated with the accumulated rainfall of 7.8 mm and 260.6 mm recorded throughout the entire dry season and rainy season, respectively, with a difference of 252.8 mm between the two seasons (Pernambuco Water and Climate Agency - *Agência Pernambucana de Águas e clima* - APAC, 2025). According to Tomiozzo et al. (2024), the ideal temperature for cut sunflower is 28 ºC, with the dry season showing values closer to the ideal range.

The R1 stage, characterized by the appearance of the flower bud, occurred at 23 DAS in the dry season, while in the rainy season it appeared at 33 DAS (Fig. 6A). During the dry season, the R4 stage (appearance of the yellow coloration of the ligulate flowers) occurred at 40 DAS (Fig. 6B). After this stage, 48 hours later, 60% of the marked plants reached the harvest point, characterized as the R5 stage (Fig. 6C), with the remaining flowers reaching this stage within 72 hours, in accordance with Silva et al. (2025), who also observed in the field that stages de time between R4 and R5 is very short, 48 hours. During the rainy season, the R4 stage (appearance of the yellow coloration of the ligulate flowers) occurred at 55 DAS and the R5 stage occurred 3 to 4 days later, around 58 DAS. The detection of these stages was possible with the help of images captured by the ESP32-CAM camera, which enabled monitoring them (Fig. 6 and 7).

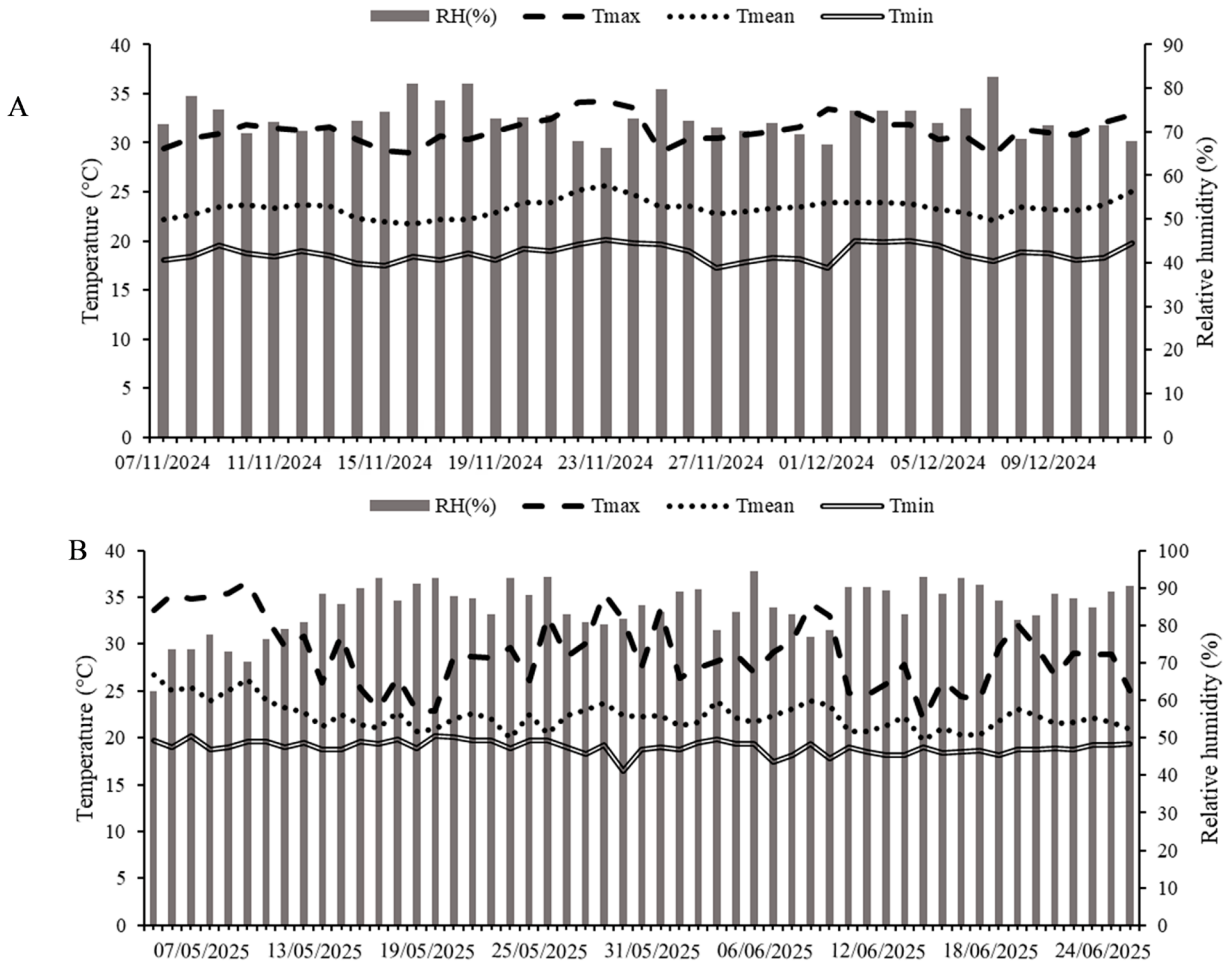

Fig. 5. Daily maximum temperature (Tmax), mean temperature (Tmean) minimum temperature (Tmin), and mean relative humidity (RH), during the dry season (A) rainy season (B) during the developmental cycle of Vincent's Choice hybrid cut sunflower.

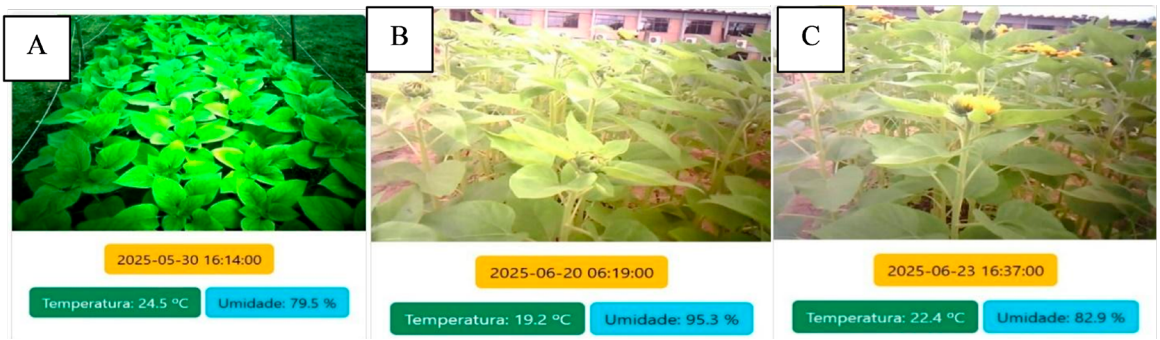

Fig. 6. Developmental stages of (A) visible flower bud (R1 stage) at 33 days after sowing (DAS), (B) visible petal color (R4 stage) at 55 DAS, and (C) petals at 90º from the capitulum disc at (R5 stage) 58 DAS of the hybrid cut sunflower Vincent's Choice recorded by the ESP32-CAM during the rainy season.



Fig. 7. Photos captured by the ESP32-CAM throughout the developmental cycle of the hybrid sunflower Vincent's Choice during the rainy season.

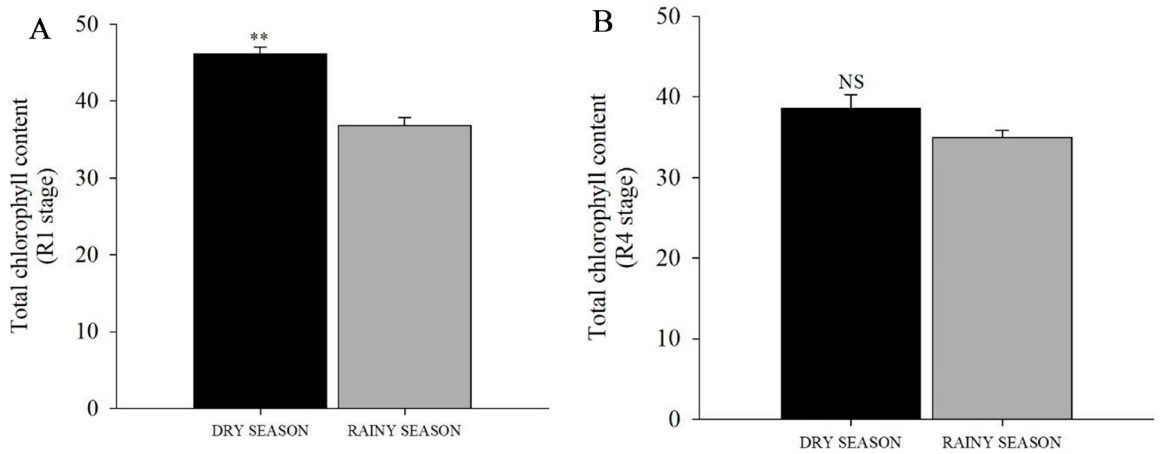

Fig. 8. Total chlorophyll indices at the R1 stage (visible bud) and R4 stage (visible petal color) of the hybrid cut sunflower Vincent's Choice during the dry and rainy seasons. Asterisks indicate significant difference at 5% (*) or 1% (**) according to the Tukey test between the dry season and the rainy season for each variable.

Air temperature and humidity are key meteorological variables that drive sunflower development and therefore are essential for producers in planning sales, as harvesting at the R5 stage facilitates transportation due to the arrangement of the petals, reducing damage to the bud and ensuring longer flower longevity. Detailed knowledge on the dynamics of the development stage sequence throughout plant life cycle is crucial for planning and implementing management practices and sustainable production, increasing both yield and the quality of the final product (Silva et al., 2025; Fonseca et al., 2026). Monitoring development through technology and digital tools further enhances efficiency in the use of time and resources by the producer, which has the potential to increase profitability in the entire flower industry chain.

Regarding chlorophyll indices, it was observed that the average values of total chlorophyll were higher in the R1 stage (visible bud) in the dry season compared to rainy season, with high statistical significance ($p < 0.01$). This difference may be associated with higher daily solar radiation and more stable and higher daily mean temperatures (22.9 ºC and 23.8 ºC) during the dry season, which favor greater photosynthetic activity and accumulation of chloroplast pigments (Fig. 8A). In contrast, at the R4 stage (Fig. 8B), (visible petal color), no significant differences were observed, possibly indicating

low chloroplast activity and consequently a reduction in total chlorophyll content.

Fig. 9 shows the gas exchange data at the R1 and R4 stages during the dry season. Significant differences were observed for Instantaneous Water Use Efficiency (Fig. 9E) and transpiration (Fig. 9C). These results indicate that at the R4 stage, plants have a higher transpiration rate, mainly due to higher temperature rates and increased water use efficiency for the flowering phase and capitulum growth. A progressive increase in stomatal conductance was also noted (Fig. 9B), resulting in greater water loss through transpiration. According to Silva et al. (2022), strategically, plants use water more efficiently when climatic conditions lead to higher evapotranspiration. Due to meteorological conditions and no clear days, it was not possible to measure gas exchange variables during the rainy season.

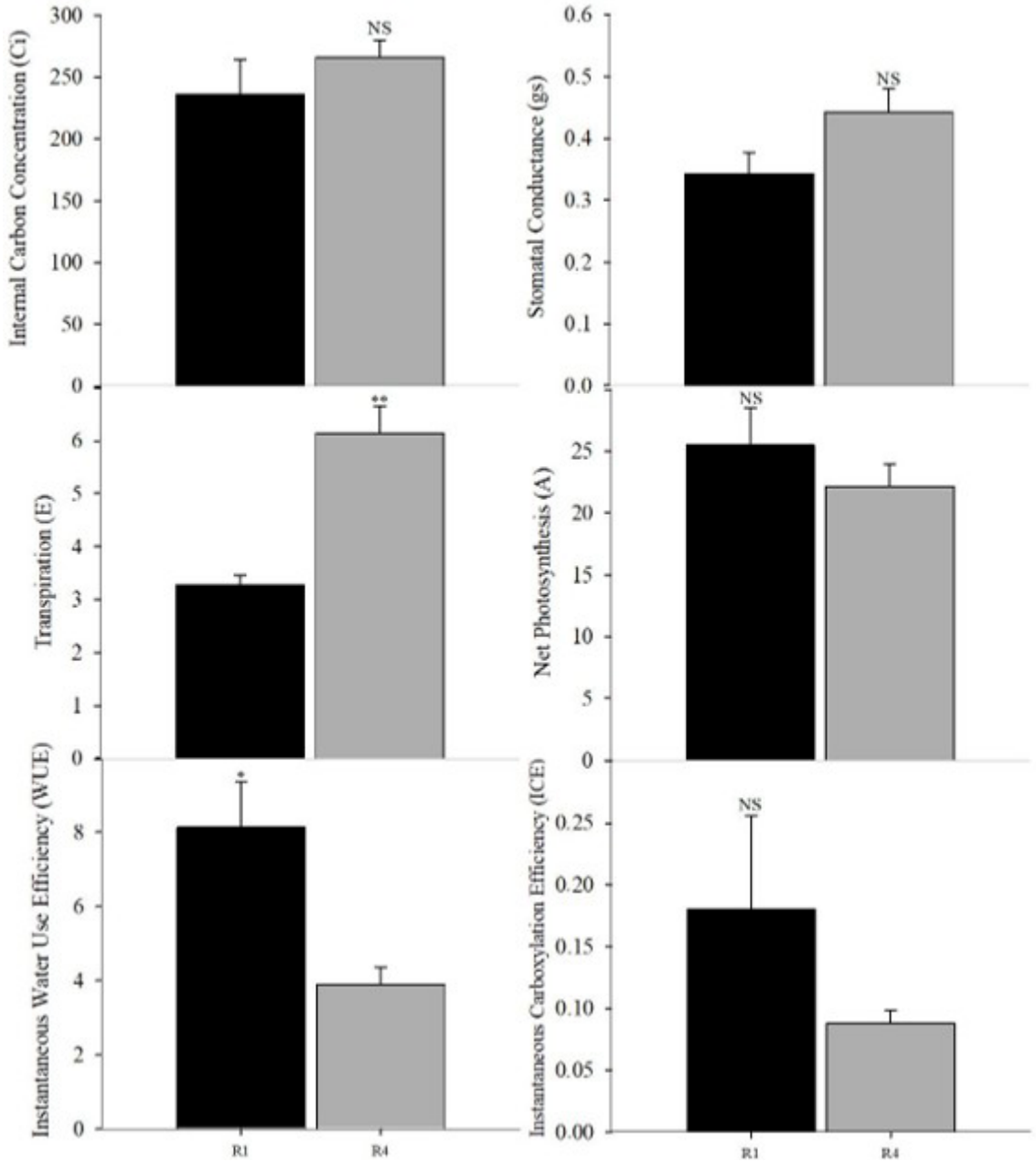

Fig. 9. Gas exchange variables at the R1 and R4 developmental stages of the hybrid cut sunflower Vincent's Choice during the dry season: (A) Internal Carbon Concentration (Ci), (B) Stomatal Conductance (gs), (C) Transpiration (E), (D) Net Photosynthesis (A), (E) Instantaneous Water Use Efficiency (WUE), and (F) Instantaneous Carboxylation Efficiency (ICE). Asterisks indicate significant differences at 5% (*) or 1% (**) according to the Tukey test between developmental stages (R1 and R4) for each variable. NS indicates no significant difference.

The inflorescences, in both the dry and rainy seasons, showed vigorous flower buds, well-formed petals without damage, as well as an appropriate uniform, intense color and aesthetic characteristics that are suitable and most valued by the consumer (Fig. 10).

The mean stem diameter reached 14.7 mm (Fig. 11A) while the diameter of the partially opened capitulum was 51.8 mm during the dry season (Fig. 11B). Both flower yield components were statistically different from those during the rainy season, where stem diameters of 10.6 mm and partially opened capitulum of 45.6 mm were observed, with a reduction of 27.9% and 11.9%, respectively. However, both flower yield components met the minimum diameter for commercialization, the minimum diameter for partially opened capitulum of 45 mm, and minimum diameter for fully opened capitulum of 55 mm (IBRAFLOR 2023).

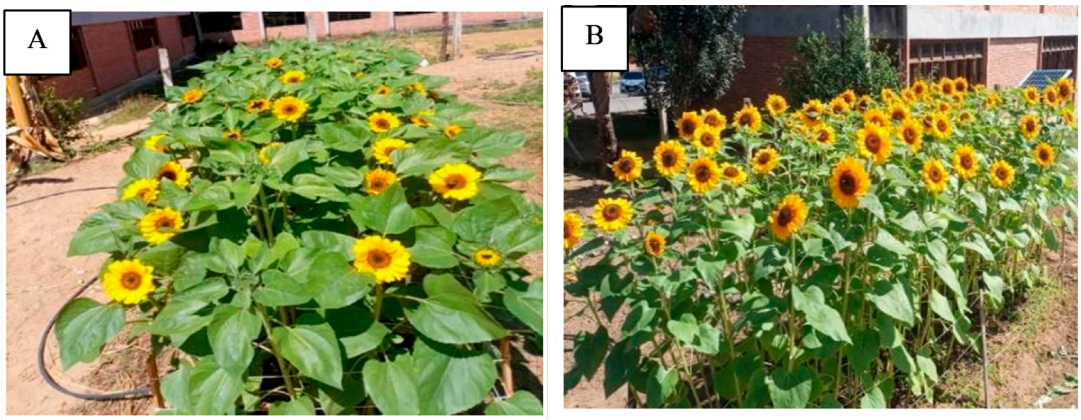

Fig. 10. Inflorescences of the hybrid cut sunflower Vincent's Choice produced in the (A) Dry season and in the (B) Rainy Season.

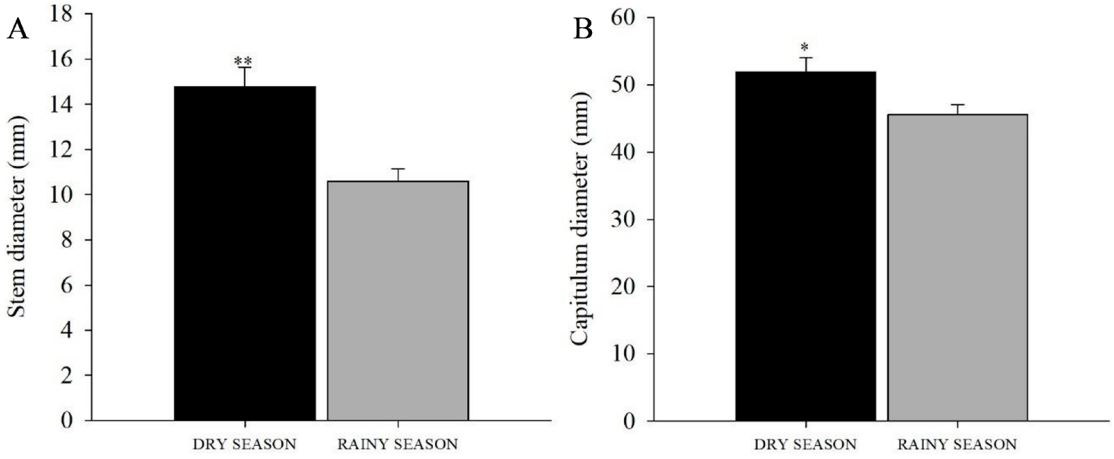

Fig. 11. (A) Stem diameter and (B) capitulum diameter of the hybrid cut sunflower Vincent's Choice during the dry season and the rainy season. Asterisks indicate significant difference at 5% (*) or 1% (**) according to the Tukey test between the dry season and the rainy season for each variable.

The Pearson correlation analysis revealed significant positive and negative correlations among the variables ($p < 0.05$), with r values varying from -0.91 to 0.99 (Fig. 12). Leaf area explains a large part of the variability in capitulum diameter (r = 0.89), which is ecophysiologically meaningful as leaf area intercepts solar radiation used for photosynthesis which in turn produces photoassimilates for the growth of reproductive organs such as the capitulum. Another relevant positive correlation was observed between the transpiration rate and capitulum diameter (r = 0.79). Physiologically, these two variables are related as transpiration is associated with adequate water availability in the soil, plenty of water absorption by roots, and CO_2 intake by open stomata so that plants with a high transpiration rate have high rates of growth and development and produce larger capitulums.

Leaf area also showed a positive correlation with transpiration (r = 0.70), which is also biologically meaningful as larger leaves intercept greater intensity of solar radiation, which results in an increased transpiration rate. Stomatal conductance showed a positive correlation with transpiration (r = 0.74), which is also physiologically expected as the stomata are the major pathway for water exchange between the mesophyll and the air boundary layer near the leaves. Regarding negative correlations, a strong negative correlation between internal carbon concentration and net photosynthesis rate (r = −0.91) stood out. This result is also physiologically meaningful as the photosynthetic rate increases there is greater consumption of CO_2 inside the leaves, reducing its internal concentration (Taiz et al., 2021, Walter et al., 2015).

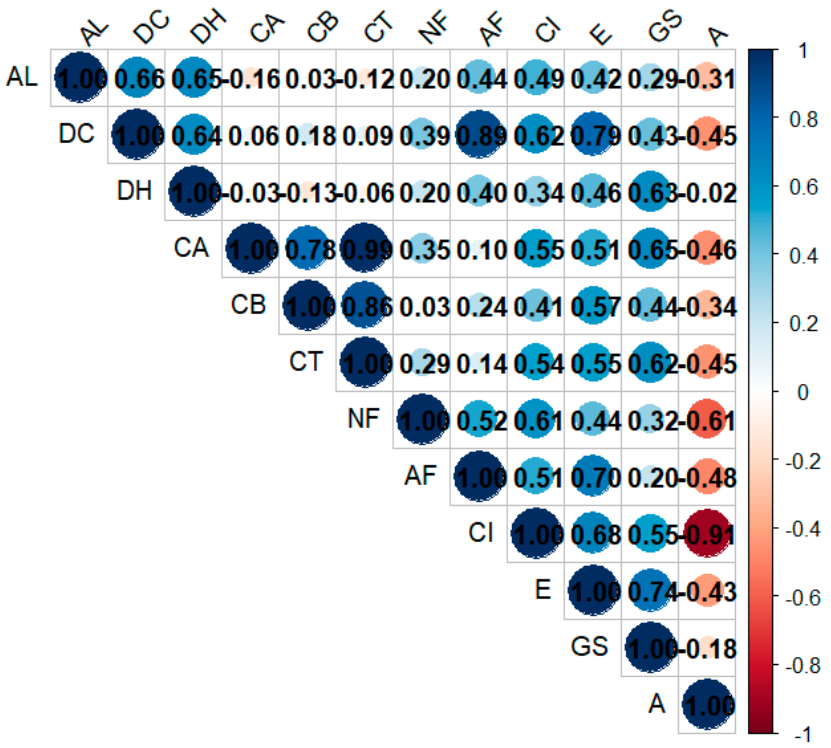

Fig. 12. Pearson correlation for values growth, development, physiological and gas exchange variables of the hybrid cut sunflower plants Vincent's Choice grown in the dry and in the rainy seasons. PH: plant height, CD: capitulum diameter, SD: stem diameter, Chl a: chlorophyll a, Chl b: chlorophyll b, Chl t: total chlorophyll, LN: number of leaves, LA: leaf area, IC: internal carbon concentration, E: transpiration, GS: stomatal conductance, A: net photosynthesis.

Conclusions

The dry season provided meteorological conditions that led to a shorter development cycle, with a larger stem and capitulum diameter in cut sunflowers. The automated monitoring system proved to be functional and efficient in monitoring environmental conditions and plant development, highlighting its potential as an accessible Agriculture 4.0 solution for optimizing flower cultivation. Thus, the use of the ESP32-CAM integrated with a mobile app, named GirassolCam, emerges as a promising tool for monitoring cut sunflower development and intelligent crop management, especially in semi-arid regions, contributing to more sustainable and efficient agronomic management practices in the flower production system.

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Author Contribution

LZA: Conceptualization, Writing – Original Draft, Writing – Review & Editing. FAL: Conceptualization, Writing – Original Draft, Writing – Review & Editing. JSBC: Methodology, Writing – Original Draft, Writing – Review & Editing. NAS: Methodology, Writing – Original Draft, Writing – Review & Editing. AMFB: Methodology. AFM: Methodology. GDSS: Methodology.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

All the research data is contained in the manuscript.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used ChatGPT (OpenAI) to assist with English language revision, grammar correction, and improvement of text clarity and readability. After using this tool/service, the author(s) reviewed and edited the content as needed and took(s) full responsibility for the content of the publication.

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