Kavga A *et al*. (2024)
Notulae Botanicae Horti Agrobotanici Cluj-Napoca
Volume 52, Issue 4, Article number 14168
DOI:10.15835/nbha52414168
Research Article

The impact of greenhouse integrated photovoltaics on *Aloe vera* cultivation

Angeliki KAVGA[1*], Vasileios THOMOPOULOS[2], Sylvia MANGANI[3], Spyros KREMMYDAS[3], Theodoros PETRAKIS[1]

[1]*Department of Agriculture, University of Patras, EL26504, Greece; akavga@upatras.gr (A.K.) (*corresponding author); tpetrakis@ac.upatras.gr (T.P.)*
[2]*Department of Computer Engineering and Informatics, University of Patras, EL26504, Greece; vthomopoulos@upatras.gr (V. T.)*
[3]*Biochemical Analysis & Matrix Pathobiology Research Group, Laboratory of Biochemistry, Department of Chemistry, University of Patras, EL26504, Greece; up1111418@upatras.gr (S.M.); up1073639@ac.upatras.gr (S.K.)*

Abstract

In recent years, the global demand for medicinal plants has been rising steadily. This study focuses on cultivating *Aloe vera* within a large-scale, pilot smart greenhouse installed at the University of Patras, Greece. The integration of advanced Internet of Things (IoT) technologies, sensors, and the KYTION cablebot robotic device plays a crucial role in monitoring the cultivation process and deriving valuable insights. The greenhouse structure presented in this study not only recognizes these challenges but actively addresses them through state-of-the-art IoT technology-based measurements. Preliminary quantitative results indicate that cultivating *A. vera* in greenhouses significantly enhances blooming and production compared to open-field cultivation. This promising approach addresses the growing demand for *A. vera* specifically and medicinal plants in general. Additionally, it maximizes the use of available arable land, labor, water, and energy, ensuring stable production under unstable and variable climatic conditions. The study aims to control and automate the microclimate, optimizing conditions for *A. vera* growth within a controlled digital environment. By offering insights into the intersection of smart agricultural practices, technology-driven measurement and automation, and ad-hoc crop-specific cultivation strategies, this research provides a promising pathway for sustainably enhancing *A. vera* cultivation in controlled environments.

Keywords: GIPVs; microclimate control; robotic system; shading; smart agriculture; smart greenhouse

Introduction

In the era of Smart Agriculture, technological advancements have enabled greenhouse systems to provide fully controlled environments, where parameters such as temperature, relative humidity, and light intensity can be precisely adjusted to maintain optimal microclimates. Utilizing computers, robotic systems, and the Internet of Things (IoT), these controlled environments foster ideal growing conditions and enhance the production of crops like *Aloe vera* (Aslan *et al*., 2022).

Received: 01 Oct 2024. Received in revised form: 24 Oct 2024. Accepted: 11 Nov 2024. Published online: 15 Nov 2024.
From Volume 49, Issue 1, 2021, Notulae Botanicae Horti Agrobotanici Cluj-Napoca journal uses article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

Integrating these advanced technologies into greenhouse cultivation offers a sustainable option for the agricultural industry, allowing farmers to boost production and improve crop efficiency. Essential tools for achieving these goals include monitoring the environment and automating processes such as heating, cooling, and watering (Dagar *et al*., 2022).

Effective greenhouse management requires the deployment of various sensors and the collection of extensive data (Monisha *et al*., 2022). Handling this data necessitates significant computational power. Highly accurate IoT sensors, which record microclimate data like temperature, humidity, and carbon dioxide (CO_2) levels, facilitate real-time monitoring and management by connecting equipment such as sensors and cameras to the internet. This connectivity enables quick decision-making to mitigate adverse crop outcomes (Farooq *et al*., 2022).

The integration of robotics further expands the potential for automating numerous operations, including heating, cooling, and lighting, by activating the appropriate systems. Working in conjunction with sensors, IoT, and Decision Support Systems (DSS), robotic systems can fully manage greenhouse operations (Brenes *et al*., 2024). In this study, the KYTION (Patras, Greece) device, a cablebot, was employed. The KYTION cablebot represents an innovative solution for data collection and monitoring in greenhouse environments, revolutionizing smart agriculture practices. Equipped with brushless motors for seamless movement along cables at speeds up to 3.5 m^*s^{-1}, the cablebot ensures efficient and precise traversal within the greenhouse. Its advanced control system, managed by an Arduino Pro Mini, orchestrates data collection intervals and energy conservation measures through automatic relay mechanisms. With built-in sensors and communication capabilities facilitated by Xbee technology, the cablebot seamlessly collects and transmits encrypted data packets to the coordinator, enabling real-time monitoring and control of irrigation and fertilization processes based on analyzed environmental data. The cablebot's robust design ensures reliable operation across a wide temperature range (-5 °C to 45 °C), with redundant backup systems safeguarding against individual subsystem failures. Overall, the KYTION cablebot represents a cutting-edge solution for greenhouse management, enhancing agricultural productivity and sustainability (Thomopoulos *et al*., 2021).

Aloe vera, ALOE L., Burm.F. is an integral part of daily life due to its medicinal properties, which include bioactive compounds such as polysaccharides, glycoproteins, anthraquinones, and antioxidants. These compounds are known for their anti-inflammatory, antimicrobial, and wound-healing properties (Surjushe *et al*., 2008). *A. vera* comprises over 250 species, with an ideal temperature range for growth between 20 °C and 24 °C. Although *A. vera* is drought-tolerant, excessive water can harm the crop. Optimal growth conditions require well-drained soil, avoidance of low valley areas, low sodium irrigation water, and relatively acidic soil (Prisa *et al*., 2021).

This review examines various aspects of *A. vera* cultivation in greenhouses. Studies include Tavali and Ok (2022), who compared the effects of heat-treated and unheated vermicompost on calcareous soil properties and organic *A. vera* growth in Mediterranean greenhouse conditions, and Golmohammadi (2022), who discussed *A. vera* cultivation in the desert regions of Iran, particularly South Khorasan and Semnan provinces. Another study by Gutiérrez *et al*. (2021) focused on IoT's role in greenhouse agriculture, emphasizing the constant monitoring and regulation of environmental conditions critical for *A. vera* growth. Martínez-Padrón *et al*. (2021) explored the incidence of *Fusarium oxysporum* by*Trichoderma spp*. in greenhouse and field conditions. Rodríguez-García *et al*. (2007) investigated the physiological responses, growth, and yield of *A. vera* in greenhouses under different soil water potentials, finding that lower leaf temperatures increased stomatal resistance and decreased growth rates. De Oliveira *et al*. (2009) presented a comprehensive protocol for large-scale micropropagation of *A. vera* in greenhouse conditions, while Rea *et al*. (2009) studied the use of composts derived from olive mill waste and green waste as components of growing media for potted *A. vera* plants in greenhouses.

Materials and Methods

Experimental greenhouse

The greenhouse utilized for this research is part of the Plant Physiology Laboratory within the Department of Biology at the University of Patras, located on the university premises (38° 17' 27.9" N, 21° 47' 23.9" E). It is divided into four distinct sections, with a total width of 12.8 m and a length of 16.39 m. The ridge is oriented along the East-West axis, mirroring the characteristics of commercial greenhouses. The structure is made from variously sized steel and aluminium components, with 4 mm glass panes used for covering. Additionally, the greenhouse features a natural ventilation system, including roof and side wall windows.

The section designated for *Aloe vera* cultivation is located on the northern side of the entire greenhouse complex. This unit measures 3.2 m in width and 16.39 m in length, with ridge and gutter heights of 3.9 m and 3.22 m, respectively. The covered area for this unit is approximately 50 m^2.

The Kytion robotic system was used to record the microclimatic conditions inside the greenhouse, such as temperature (°C) and relative humidity (%). Measurements were taken every 10 minutes, and for this study, the daily average values for both parameters were calculated and utilized. On the other hand, for recording Global Horizontal Irradiance (GHI - $W{*}m^{-2}$), two CMP3 pyranometers by Kipp & Zonen were used. The pyranometers were positioned along the line bisecting the width of the studied construction unit and at locations corresponding to ¼ and ¾ of the greenhouse's length. The GHI values used in this study are the average values recorded by the two pyranometers, providing a general view of the radiation entering the greenhouse.

On the greenhouse's roof, six semi-transparent photovoltaic modules (bifacial type) are installed, with a width of 1033 mm, a length of 2089 mm, and a thickness of 5.5 mm. The number of solar cells is 80, and they are evenly distributed in four rows along the length of each module. The photovoltaic modules are installed on the south-facing inclined plane of the greenhouse roof to maximize energy production, particularly during winter when the sun is at a lower angle. A specially designed algorithm, based on the characteristics of the greenhouse, the photovoltaic modules, and the sun's position, was used to determine the shading caused by the semi-transparent photovoltaics. This algorithm calculated the average daily percentage of shaded areas for planting rows A and B (Petrakis *et al*., 2023; Petrakis *et al*., 2024).

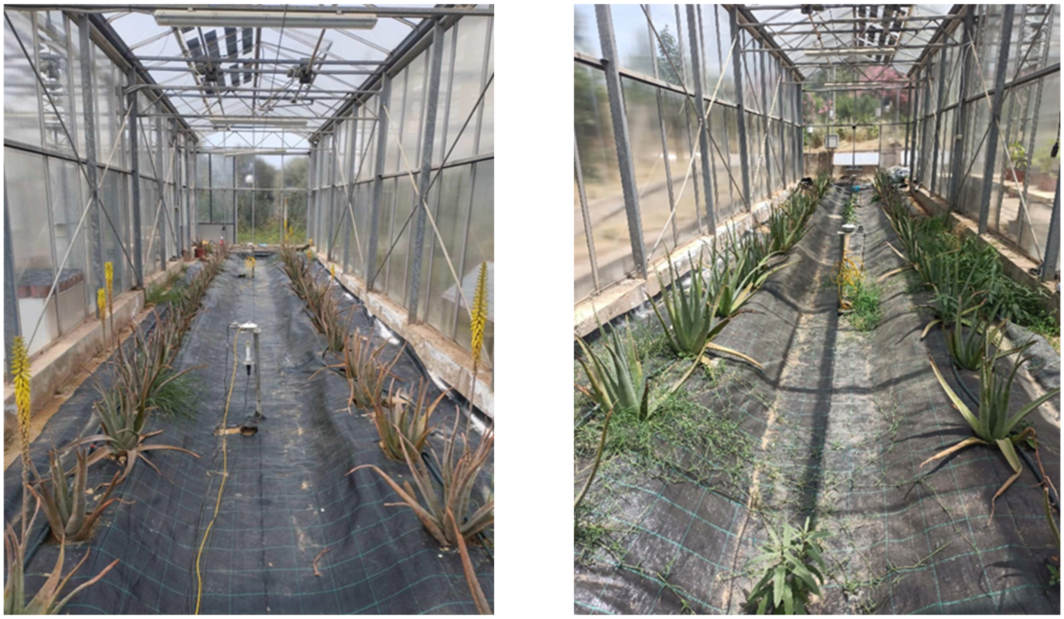
Aloe vera cultivation

Inside the greenhouse unit designated for horticultural cultivation, *A. vera* plants were arranged in two parallel rows, spaced about 1.5 m apart. A total of 42 *A. vera* plants, each four years old and initially grown in open fields, were planted for this experiment. Each row was approximately 15 m long, with 21 plants positioned roughly 80 cm apart (Figure 1).

To prevent weed growth, the ground was covered with plastic sheeting. Irrigation was provided by a 20 mm diameter drip tube placed beneath the cover, delivering 2 litres per hour per dripper. Each plant had a dedicated dripper for irrigation.

Measurements were taken on the crop, specifically the length (in cm) of a standard leaf from each plant, recorded from the planting date (December 5, 2023) until the conclusion of the experiment (March 15, 2024). Leaf length was measured from the stem to the leaf edge. On January 14, 2024, a liquid biostimulant fertilizer (seaweed-based, derived from *Ascophyllum nodosum*) was applied to promote root system development and overall plant growth.

Finally, in addition to these two planting rows, the research also takes into account an Aloe crop located outside the greenhouse but nearby, under similar meteorological conditions and with zero shading.



(a) (b)

Figure 1. *Aloe vera* cultivation into the arable area of the greenhouse (a) at the beginning of the cultivation (05/12/2023) and (b) more recently, after the end of the measurements (06/06/2024)

Sample preparation and extraction methodology

In order to prepare the sample for further extraction, we developed a modification of the previously described protocol (Petrakis *et al*., 2024). Particularly, the *A. vera* leaves utilized in this study were firstly stored at −20 °C. For the extraction process, three leaves from each line (denoted as A, B and C) were allowed to thaw at room temperature (RT). A small section near the base of each leaf was then cut, weighed after peeling, and 5 ml of pure *A. vera* gel was obtained from each sample. The gel samples were placed in vials, frozen gradually, and then freeze-dried overnight. Subsequently, the lyophilized samples were re-weighed and 3 ml of 70:30 v/v [methanol (MeOH)–2x distilled (2d) water] was added as the extraction solvent. The homogenates were placed for 1 hour in a mild agitation shaker to facilitate the extraction. Centrifugation at 4000 rpm for 10 minutes at RT was performed to separate the supernatants, which were collected and used for further chemical analyses.

Total phenolic content and free-radical-scavenging activity Analyses

The total phenolic content (TPC) in the *A. vera* extracts was determined with Folin–Ciocalteu's reagent (Panreac, Barcelona, Spain) (Ainsworth and Gillespie, 2007). To this end, 0.125 mL of each sample was combined with 0.75 mL of 2d water and 0.125 mL of the Folin–Ciocalteu reagent. The resulting solution was allowed to incubate for 6 min. Subsequently, 2 mL of a 5% (w/v) sodium carbonate solution was added, and the mixture was left to incubate for an additional 90 min at RT, in the absence of light. The absorbance of the samples was measured at 760 nm using a TECAN photometer. The obtained results are expressed as mg of gallic acid equivalent (GAE) per mg of *A. vera* dry weight, representing the average of three measurements for each sample (Figure 2).

The free-radical-scavenging activity of the extract, representing the antioxidant capacity of the samples, was evaluated using the 1,1-diphenyl-2-picryl-hydrazyl (DPPH) method (Golpour *et al*., 2021). More specifically, a 0.2 mM DPPH solution (Cayman Chemical, Ann Arbor, MI, USA) was prepared fresh in MeOH. In this study, 0.02 mL of each sample was combined with 0.180 mL of 0.2 mM DPPH solution, and the resulting solution was allowed to incubate for 30 min at RT, in the absence of light. The absorbance of the samples was measured at 517 nm using a TECAN photometer. The obtained results are expressed as μg of L-ascorbic acid equivalent (AAE) per mg of *A. vera* dry weight, representing the average of three measurements for each sample.

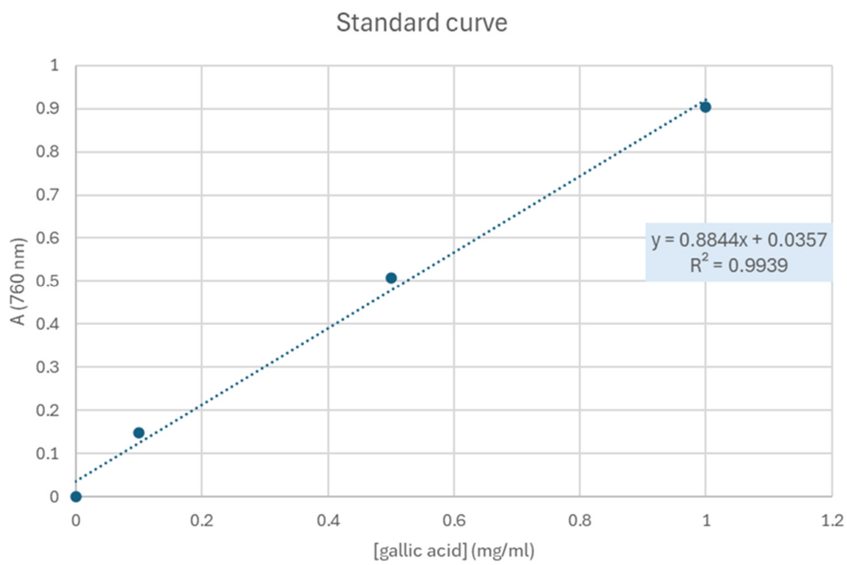


Figure 2. GA standard calibration curve using the TPC method
The trend line (dashed line) equation is used to determine the concentration of unknown samples based on their absorbance values.

Gallic acid and L-ascorbic acid calibration curves

To obtain a 1% solution of gallic acid (GA) (10 mg/mL), 0.15 g of GA (Sigma-Aldrich, St. Luis, MO, USA) was dissolved in 15 mL of 70:30 [methanol (MeOH)–2d water]. Subsequently, a standard GA curve was established by diluting the standard solution of GA to concentrations of 0.1, 0.5, and 1 mg/mL in 70:30 [methanol (MeOH)–2d water]. The calibration curve was obtained using the TPC method, as described above. The equation obtained is represented by Equation (1) with a perfect linear regression of R^2 = 0.9939 (Figure 2).

$$y = 0.8844\times + 0.0357 \quad (1)$$

where y represents the absorbance at 517 nm and x represents the respective L-ascorbic acid concentration.

To obtain a 1 mg/mL solution of L-ascorbic acid, 0.03 g of L-ascorbic acid (Acros Organics, Fair Lawn, NJ, USA) was dissolved in 30 mL of 2d water. Afterwards, a standard L-ascorbic acid curve was established by diluting the standard solution of L-ascorbic acid to concentrations of 75, 100, 150 and 200 μg/mL in 2d water. The calibration curve was obtained using the DPPH method, as described above. The equation obtained is represented by Equation (2) with a linear regression of R^2 = 0.9817 (Figure 3).

$$y = 0.4798x + 3.1195 \quad (2)$$

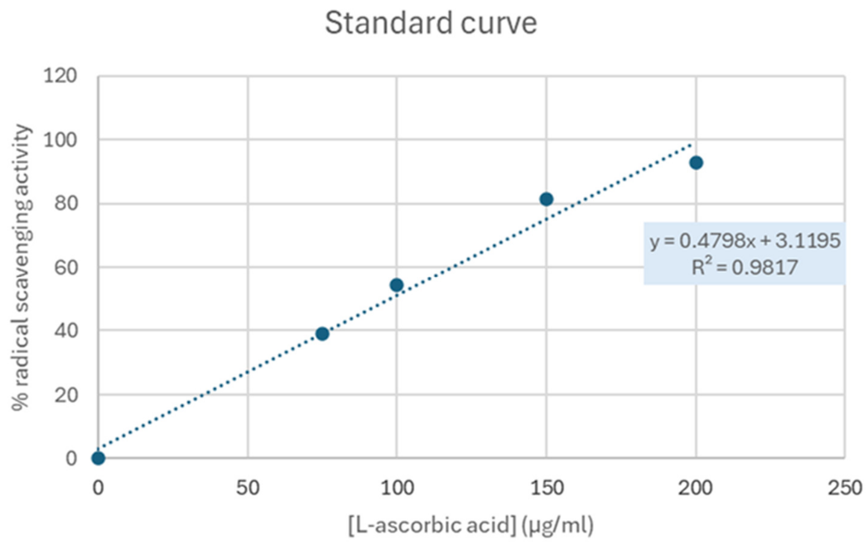


Figure 3. L-ascorbic acid standard calibration curve using the DPPH method
The trend line (dashed line) equation is used to determine the concentration of unknown samples based on their absorbance values.

Statistical analysis

The reported values for the growth, morphological, and yield measurements are expressed as the mean ± the standard error (SE).

The reported values are expressed as the mean ± the standard deviation (SD) of the experiments in triplicate. Statistically significant differences were evaluated using Tukey's test to determine statistical differences between each data set of the three lines (A, B and C). Differences were considered statistically significant at the level of $p \leq 0.05$, indicated by an asterisk (*). The statistical analysis and graphs were made using GraphPad Prism 8.0.1 (GraphPad Software, San Diego, CA, USA).

Results and Discussion

The graphs in Figures 4, 5, and 6 depict the microclimatic conditions inside the greenhouse throughout the experiment. These parameters include the mean daily temperature (°C), mean daily relative humidity (%), and mean daily total solar radiation measured horizontally (excluding zero radiation values during the night) (W/m^2). The black line represents the time series of these parameters, while the red line shows trends modelled using a 2nd-degree polynomial.

The graphs indicate that the mean daily temperature ranged from 9.69 to 21.76 °C, the mean daily relative humidity varied between 49.39% and 90.77%, and solar radiation values ranged from 22.67 to 201.98 W/m^2.

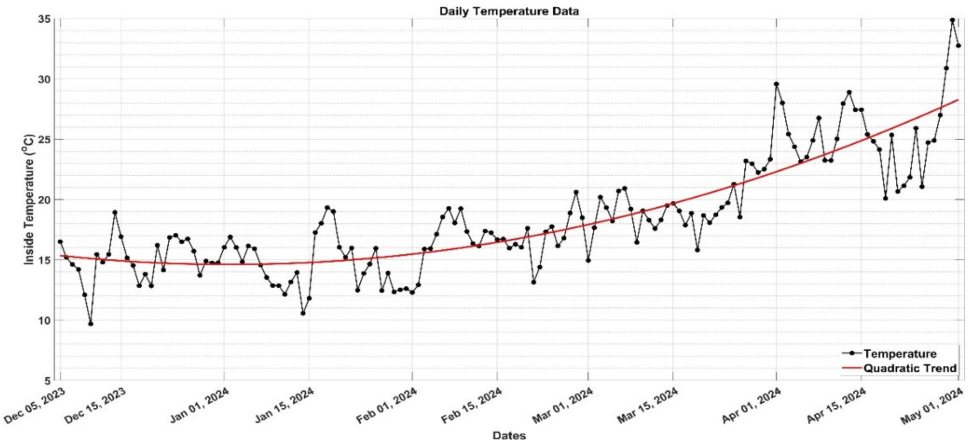


Figure 4. Mean daily temperature inside the greenhouse for the period of the experiment, combined with the corresponding trend

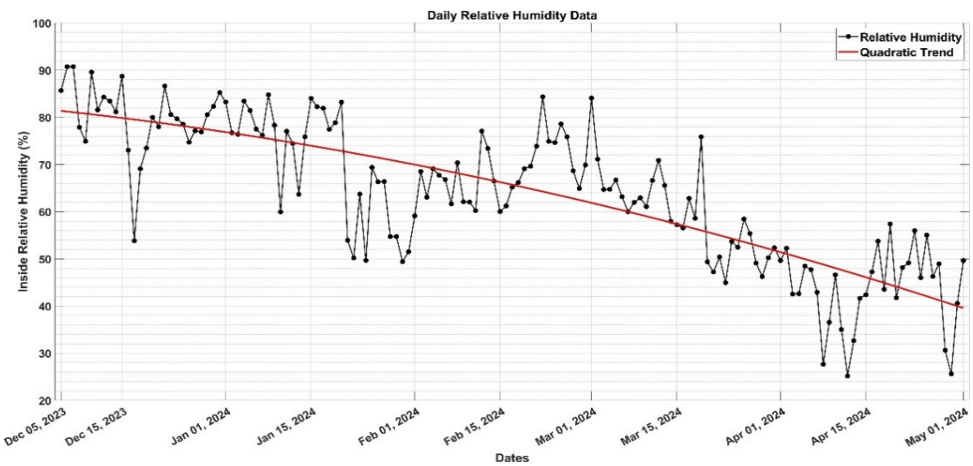


Figure 5. Mean daily relative humidity inside the greenhouse for the period of the experiment, combined with the corresponding trend

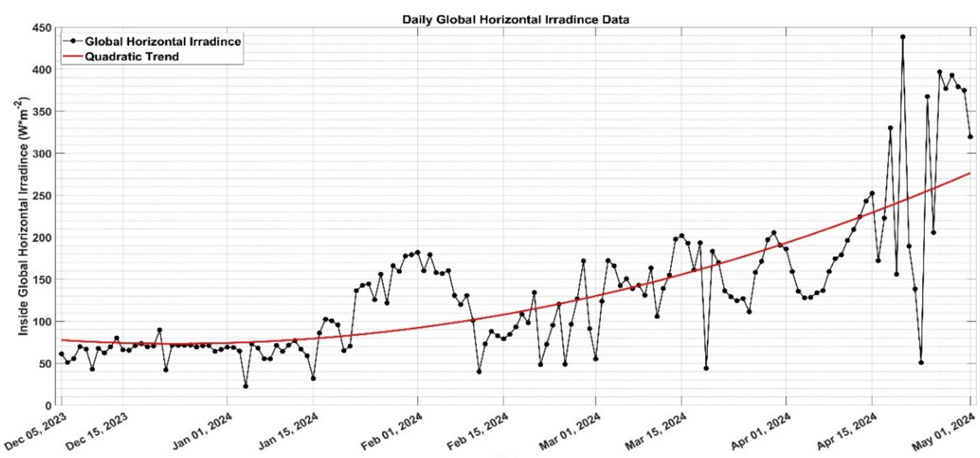


Figure 6. Mean daily global horizontal irradiance inside the greenhouse for the period of the experiment, combined with the corresponding trend

The first batch of flowering, comprising 9.5% of the total number of plants, occurred on 30/12/2023, just 25 days after planting. It is noteworthy that the planting shock was significantly less than in open cultivation. By our second measurement on 14/01/2024, we observed the development of new leaves, averaging 2.3 leaves per plant. By the third measurement on 29/01/2024, the percentage of flowering had increased to 19%. Subsequent measurements indicated significant development in the *A. vera* plants, with existing flowers continuing to bloom and new leaves developing while the existing ones remained steady. Tables 1 and 2 present the measurements for the Aloe leaves' length in planting lines A and B, respectively.

Table 1. Aloe leaves' length measurements (in cm) for planting line A

Plant (Line A)	Dates									
	5/12/2023	15/12/2023	1/1/2024	15/1/2024	1/2/2024	15/2/2024	1/3/2024	15/3/2024	01/04/2024	15/04/2024
1	3	3	12	18	22	24	26	26	30	34
2	4	4	10	16	19	21	24	24	30	35
3	7	7	15	20	23	25	27	27	28	33
4	10	10	13	19	21	23	25	25	29	35
5	9	11	14	21	24	26	28	28	33	39
6	12	15	22	27	30	31	33	33	37	41
7	15	19	26	31	33	34	35	35	35	40
8	10	10	16	21	24	28	31	31	35	39
9	5	6	15	20	24	26	30	30	34	39
10	5	6	14	19	22	26	29	29	37	41
11	20	20	22	26	28	30	32	32	37	42
12	10	10	17	22	25	27	29	29	35	40
13	10	11	15	21	24	27	29	29	36	40
14	13	13	20	24	26	28	32	32	39	43
15	18	18	23	26	29	31	34	34	39	41
16	1	3	12	18	22	26	29	29	35	42
17	20	20	27	30	32	35	35	35	38	42
18	22	23	29	31	33	35	35	35	39	40
19	11	13	20	24	27	30	30	30	36	40
20	5	7	18	23	25	28	28	28	36	41
21	5	7	17	25	29	31	31	31	36	43

Table 2. Aloe leaves' length measurements (in cm) for planting line B

Plant (Line B)	**Dates**									
	5/12/2023	**15/12/2023**	**1/1/2024**	**15/1/2024**	**1/2/2024**	**15/2/2024**	**1/3/2024**	**15/3/2024**	**01/04/2024**	**15/04/2024**
1	2	5	14	17	22	25	27	27	35	40
2	5	8	17	20	25	27	29	29	33	39
3	5	8	15	18	26	29	32	32	36	40
4	5	9	15	18	26	29	32	32	37	42
5	7	7	16	19	23	26	30	30	35	40
6	8	12	18	21	25	28	31	31	36	41
7	11	15	19	22	27	29	32	32	37	43
8	14	16	22	25	29	31	35	35	40	40
9	17	20	23	26	30	35	37	37	42	44
10	6	12	18	22	29	33	35	35	42	44
11	5	12	19	24	28	32	35	35	40	41
12	12	17	22	26	30	36	39	39	43	43
13	7	14	18	22	28	34	37	37	42	43
14	8	16	20	25	29	35	38	38	43	46
15	4	12	18	26	30	36	39	39	46	40
16	4	11	17	22	29	34	36	36	40	42
17	25	27	30	31	35	39	41	41	42	42
18	19	22	29	30	35	38	41	41	42	42
19	22	25	29	33	36	39	41	41	42	42
20	16	19	24	29	33	38	42	42	43	43
21	14	19	27	31	35	39	44	44	45	45

Regarding the development of *A. vera* leaves (Figure 7), it is noticeable that after overcoming planting stress in the first two weeks, the leaves continue to grow steadily until 01/03/2024 (for two and a half months). Following this phase, new leaves begin to grow above the older ones. This three-phase growth pattern is observed in both planting lines, with Line B exhibiting slightly faster development.

According to the graph in Figure 8, comparing the leaf sizes of the plants between the two planting rows, in combination with the shading experienced by the plants, a positive effect of shading on aloe leaf size is observed. Specifically, from 01/02 to 01/03, there is a greater increase in the leaf size of the plants in row B, which coincides with the increase in shading in row B. In contrast, the leaf size of the plants in row A remains stable during the same period. Additionally, observing the period from 15/03 to 01/04, it is noted that the increase in shading in row A causes a simultaneous increase in the leaf size of the plants, whereas in row B, with reduced shading, a smaller increase in leaf size is observed. However, while these results suggest a small positive effect of shading on aloe plants, further validation is required.

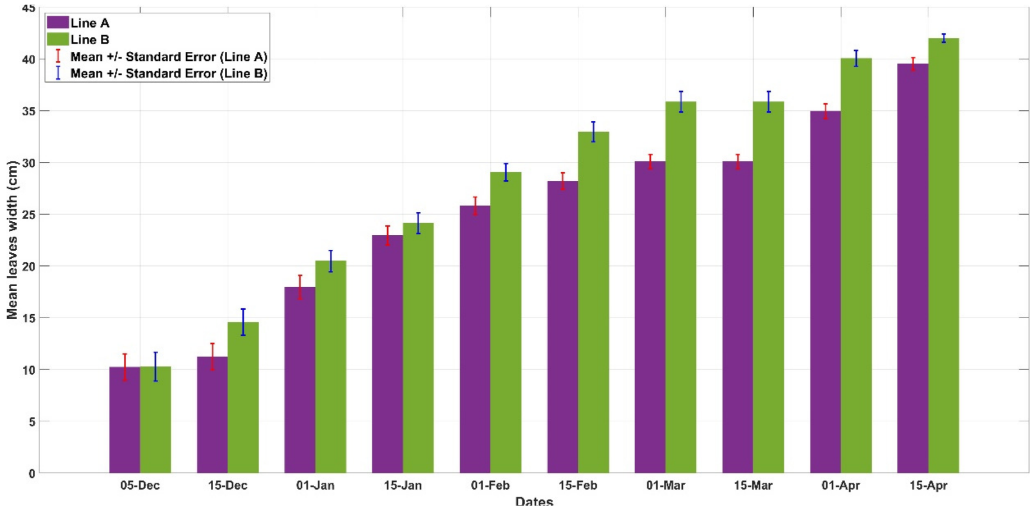


Figure 7. Mean aloe leaves' length during the experimental period for planting line A (purple) and planting line B (green) (mean ± SE, n = 21)

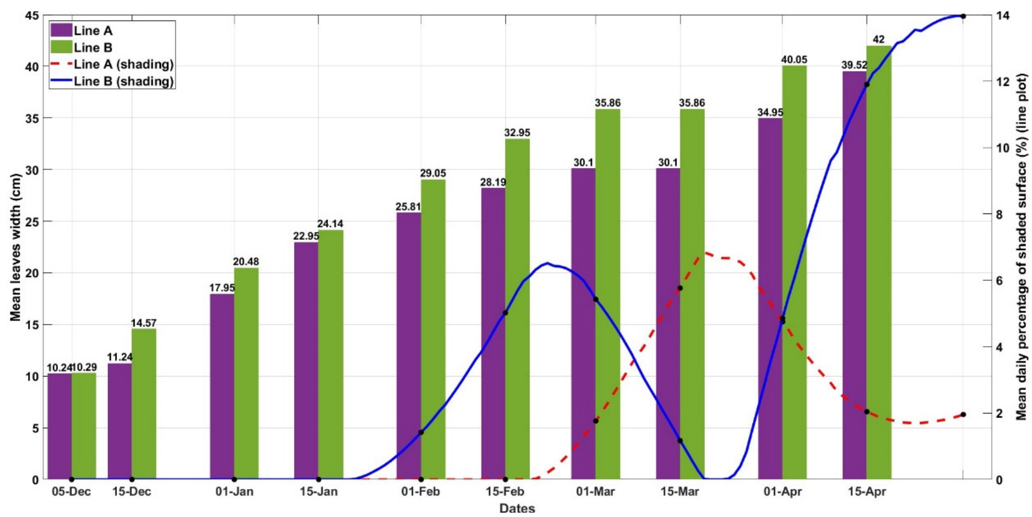


Figure 8. Mean aloe leaves' length for each planting row combined with the mean daily percentage of the shaded surface

Total phenolic content and free-radical-scavenging activity

As mentioned in the Materials and Methods Section, samples from each line underwent the TPC method for the determination of their phenolic content. The absorbance of each sample was measured at 760 nm and their TPC is calculated through the calibration curve of GA. The results are given in Figure 9. The difference between Line C and Lines A, B of *A. vera* was statistically significant, as line C showed significantly higher TPC content (> 2-fold increase) than lines A, B. The lines A and B importantly do not significantly differ each other and present a substantial TPC content. This notable difference suggests that Line C appears to possess either a higher concentration of phenolic-rich components or an increased capability for phenolic compounds biosynthesis, which could be influenced by various environmental factors, including differences in cultivation methods, that are known to affect secondary metabolite production in plants (Li *et al*., 2020).

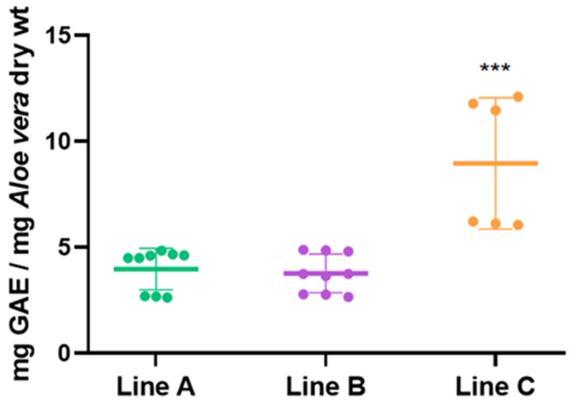


Figure 9. Results of TPC analysis in *A. vera*

The TPC in *A. vera* is expressed as mg of GAE per mg of *A. vera* dry weight. Three asterisks (***) indicate statistically significant difference ($p < 0.001$) between Line C and Lines A,B (3 samples of *A. vera* gel from lines A and B and 2 samples from line C were analyzed)

Moreover, samples from each line underwent the DPPH analysis for the determination of their free-radical-scavenging activity, which represents their antioxidant activity. The absorbance of each sample was measured at 517 nm and their antioxidant capacity is given through the calibration curve of L-ascorbic acid. The results are presented in Figure 10.

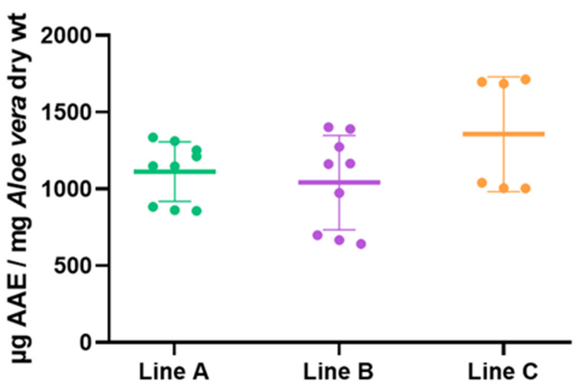


Figure 10. The results of the DPPH analysis in *A. vera*

The ability of *A. vera* leaves to scavenge DPPH is expressed as μg of AAE per mg of *A. vera* dry weight. No statistically significant differences between Line C and Lines A, B were noted (3 samples of *A. vera* gel from lines A and B and 2 samples from line C were analyzed).

Notably, all lines A, B and C showed a high free-radical-scavenging activity, despite the fact that the differences between Line C and Lines A, B of *A. vera* were not statistically significant. Notably, all lines A, B and C showed a high free-radical-scavenging activity. This may suggest that while phenolic compounds importantly contribute to the antioxidant activity of the plant, they are not the only factors involved. Other bioactive compounds present in *A. vera*, such as vitamins, polysaccharides, anthraquinones and carotenoids, also hold key roles in determining the overall antioxidant capacity. This could explain why Lines A and B, even with lower TPC compared to Line C, still exhibited similar levels of antioxidant activity (Hęś *et al.*, 2019). Further examination of these factors is a topic of future research.

Conclusions

The integration of greenhouse-integrated photovoltaics (GIPV) in *A. vera* cultivation offers promising results for both energy efficiency and plant growth. The study effectively maintained favorable microclimatic conditions inside the greenhouse, with mean daily temperatures ranging from 9.69 to 21.76 °C, relative humidity between 49.39% and 90.77%, and solar radiation values from 22.67 to 201.98 W/m^2. These conditions were conducive to the healthy growth of *A. vera* plants. *A. vera* plants showed robust development within the GIPV greenhouse, while shading seemed to have a positive effect on the leaf size of the plants. More specifically, the first flowering occurred just 25 days after planting, and significant leaf growth was observed, with new leaves continuing to develop above the older ones. This indicates a successful adaptation to the greenhouse environment with minimal planting shock compared to open cultivation. The recorded temperatures were generally within the ideal range for *A. vera* cultivation (20–24 °C), despite some low temperatures during the growth period. This suggests that the greenhouse effectively handles extreme temperature variations, providing a stable environment for *A. vera* growth. The *A. vera* plants from the greenhouse showed high total phenolic content (TPC) and free-radical-scavenging activity (DPPH analysis), indicating strong antioxidant properties. The integration of IoT technologies and robotic devices, such as the KYTION cablebot, demonstrated significant advancements in smart greenhouse agriculture. These technologies allowed for precise monitoring and management of the microclimate, promoting sustainability and efficiency in *A. vera* cultivation. The use of GIPV not only supports the energy needs of the greenhouse but also contributes to reducing the carbon footprint of agricultural practices. This dual benefit aligns with global sustainability goals and highlights the potential of GIPV systems in modern agriculture.

Authors' Contributions

Conceptualization: T.P. and V.T, Data curation: T.P., Formal analysis: T.P., S.M. and S.K., Funding acquisition: A.K., Investigation T.P., V.T., Methodology: A.K., V.T., Project administration: A.K., Resources: A.K., T.P., Software T.P., V.T., S.M. and S.K., Supervision: A.K., Validation: T.P., S.M. and S.K., Visualization: T.P., S.M. and S.K., Writing – original draft: V.T, T.P., S.M. and S.K., Writing – review and editing: A.K. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

Acknowledgements

This paper was funded in the framework of "Pilot application of greenhouse simulation of indigenous climatic conditions for the cultivation of Aloe (*A. vera*) for optimal production of Acemannan polysaccharide". M16SYN2-00282. Sub-measure 16.1–16.2 "Establishment and operation of Operational Groups of the European Innovation Partnership for agricultural productivity and sustainability", Action 2, of the Rural Development Programme 2014-2020 (RDP 407 2014-2020), Region of Western Greece, December 2022-2024.

We would like to thank the Biochemistry, Biochemical Analysis & Matrix Pathobiology Research Group, Laboratory of Biochemistry, Department of Chemistry of the University of Patras and its Director Prof. Nikolaos Karamanos for their contribution and support.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

Ainsworth E, Gillespie K (2007). Estimation of total phenolic content and other oxidation substrates in plant tissues using Folin–Ciocalteu reagent. Nature Protocols 2:875-877. *https://doi.org/10.1038/nprot.2007.102*

Aslan MF, Durdu A, Sabanci K, Ropelewska E, Gültekin SS (2022). A comprehensive survey of the recent studies with UAV for precision agriculture in open fields and greenhouses. Applied Sciences 12:1047. *https://doi.org/10.3390/app12031047*

Brenes JA, López G, Ferrández-Pastor FJ and Marín-Raventós G (2024). Usability assessment of a greenhouse context-aware alert system for small-scale farmers. Frontiers in Computer Sciences 6:1412913. *https://doi.org/10.3389/fcomp.2024.1412913*

Dagar R, Som S, Khatri SK (2018). Smart farming-IoT in agriculture. In: Proceedings of the International Conference on Inventive Research in Computer Applications (ICIRCA). pp 1052-1056. *https://doi.org/10.1109/ICIRCA.2018.8597264*

de Oliveira ET, Crocomo OJ, Farinha TB, Gallo LA (2009). Large-scale micropropagation of *Aloe vera*. HortScience 44(6):1675-1678. *https://doi.org/10.21273/hortsci.44.6.1675*

Farooq MS, Javid R, Riaz S, Atal Z (2022). IoT based smart greenhouse framework and control strategies for sustainable agriculture. IEEE Access 10:99394-99420. *https://doi.org/10.1109/ACCESS.2022.3204066*

Golmohammadi F (2022). Medical plant of *Aloe vera* in desert regions of Iran: Greenhouses, economic importance, development, extension, processing and marketing. Black Sea Journal of Agriculture 5(1):1-15. *https://doi.org/10.47115/bsagriculture.945710*

Golpour I, Ferrão AC, Gonçalves F, Correia PMR, Blanco-Marigorta AM, Guiné RPF (2021). Extraction of phenolic compounds with antioxidant activity from strawberries: Modelling with Artificial Neural Networks (ANNs). Foods 10:2228. *https://doi.org/10.3390/foods10092228*

Gutiérrez S, Rocha R, Rendón D, Bernabé JC, Aguilera L, Solanki VK (2021). Tracking greenhouses farming based on internet of technology. In: Balas VE, Solanki VK, Kumar R (Eds). Further Advances in Internet of Things in Biomedical and Cyber Physical Systems. Intelligent Systems Reference Library, volume 193. Springer, Cham. *https://doi.org/10.1007/978-3-030-57835-0_18*

Hęś M, Dziedzic K, Górecka D, Jędrusek-Golińska A, Gujska E (2019). *Aloe vera* (L.) Webb.: Natural sources of antioxidants – A review. In: Plant Foods for Human Nutrition. Springer Science and Business Media LLC. 74(3):255-265. *https://doi.org/10.1007/s11130-019-00747-5*

Li Y, Kong D, Fu Y, Sussman MR, Wu H (2020). The effect of developmental and environmental factors on secondary metabolites in medicinal plants. Plant Physiology and Biochemistry 148:80-89. *https://doi.org/10.1016/j.plaphy.2020.01.006*

Martínez-Padrón H, Rodriguez R, Herrera-Mayorga V, Paredes-Sánchez F, Teresa Ma, Martínez J, Osorio E (2021). Biocontrol of *Fusarium oxysporum* by *Trichoderma* spp. in *Aloe vera* under greenhouse and field conditions. MYCOPATH 65-73.

Monisha SR, Yalamalli VD, Numan SU, Gowda KH, Rakesh MD (2022). Greenhouse monitoring and automation system. International Research Journal of Engineering and Technology (IRJET) 9(7):2619-2625. *https://www.researchgate.net/publication/363652460*

Petrakis T, Thomopoulos V, Kavga A, Argiriou AA (2023). An algorithm for calculating the shade created by greenhouse integrated photovoltaics. Energy, Ecology and Environment 9(3):272-300. *https://doi.org/10.1007/s40974-023-00306-4*

Petrakis T, Ioannou P, Kitsiou F, Kavga A, Grammatikopoulos G, Karamanos N (2024). Growth and physiological characteristics of strawberry plants cultivated under greenhouse-integrated semi-transparent photovoltaics. Plants 13:768. *https://doi.org/10.3390/plants13060768*

Petrakis T, Thomopoulos V, Kavga A (2024). Algorithmic advancements in agrivoltaics: Modeling shading effects of semi-transparent photovoltaics. Smart Agricultural Technology 9:100541. *https://doi.org/10.1016/j.atech.2024.100541*

Prisa D, Gobbino M (2021). Biological treatments for quality improvement and production of *Aloe vera* gel. GSC Advanced Research and Reviews 09(01):054-063. *https://doi.org/10.30574/gscarr.2021.9.1.0237*

Rea E, Pierandrei F, Rinaldi S, De Lucia B, Vecchietti L, Ventrelli A (2009). Effect of compost-based alternative substrata in potted *Aloe vera* (L.) BURM. F. Acta Horticulturae 807:541-546 *https://doi.org/10.17660/ActaHortic.2009.807.79*

Rodríguez-García R, Rodríguez DJ, de Gil-Marín JA, Angulo-Sánchez JL, Lira-Saldivar RH (2007). Growth, stomatal resistance, and transpiration of *Aloe vera* under different soil water potentials. Industrial Crops and Products 25:123-128). *https://doi.org/10.1016/j.indcrop.2006.08.005*

Surjushe A, Vasani R, Saple DG (2008). *Aloe vera*: a short review. Indian Journal of Dermatology 53(4):163-166. *https://doi.org/10.4103/0019-5154.44785*

Tavali IE, Ok H (2022). Comparison of heat-treated and unheated vermicompost on biological properties of calcareous soil and *Aloe vera* growth under greenhouse conditions in a Mediterranean climate. Agronomy 12:2649. *https://doi.org/10.3390/agronomy12112649*

Thomopoulos V, Bitas D, Papastavros K-N, Tsipianitis D, Kavga A (2021). Development of an integrated iot-based greenhouse control three-device robotic system. Agronomy 11:405. *https://doi.org/10.3390/agronomy11020405*