

STUDY ON THE IMPACT OF SEMI-TRANSPARENT PHOTOVOLTAIC PANELS IN HORTIVOLTAIC SYSTEMS ON MICROCLIMATE AND STRAWBERRY PRODUCTION IN ROMANIA

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Abstract

*Hortivoltaic systems, integrating renewable energy generation with microclimate control, offer sustainable solutions for agriculture under climate change. This study examines the effects of semi-transparent photovoltaic panels on strawberry (*Fragaria x ananassa*) cultivation. Conducted at the Moara Domneasca Experimental Base in Romania, the experiment used two panel types: PV1 (48.92% transparency) and PV2 (77.01% transparency), alongside a control area. Microclimate monitoring included soil moisture, soil and air temperature, and humidity. Results showed that air temperatures under PV systems were 5.30°C lower than the uncovered control, reducing heat stress. PV panels also lowered soil temperatures (e.g., 21.86°C under PV1 vs. 22.60°C in the control) and increased soil moisture due to reduced evapotranspiration. Regarding strawberry quality, PV1 panels negatively affected fruit weight and sugar content, while PV2 panels maintained comparable sugar levels (30.33% Brix) and firmness (3.27N) to the control. These findings highlight the potential of hortivoltaic systems to optimize crop productivity in hot climates, offering dual benefits of energy production and sustainable agriculture. Future research should explore long-term impacts.*

Key words: agrivoltaics, hortivoltaic systems, semi-transparent photovoltaic panels, microclimate control, strawberry cultivation, quality, fruit firmness.

INTRODUCTION

The climate change and intensification demand for sustainable food production have generated worldwide interest in novel agricultural technologies. A potential method that is able to supply a part of these needs, is hortivoltaics, a category of agrivoltaic systems that combines photovoltaic (PV) panels with horticulture cultivation. Agrivoltaics, first proposed by (Goetzberger and Zastrow, 1982), means the simultaneous use of land for energy production and agricultural purposes. This idea has developed into several forms, such as opaque panels placed over crops, semi-transparent solar panels, and photovoltaic greenhouses (Dupraz et al., 2011; Barron-Gafford et al., 2019).

Agrivoltaic with its branch Hortivoltaic systems are more and more popular for their technical capacity to enhance light distribution, retain soil moisture, and modify crop

microclimates, especially in climate-stressed environments (Weselek et al., 2021). The European Commission recognized agrivoltaics as a significant factor in meeting renewable energy objectives, predicting that the deployment of even 1% of agricultural land may provide a photovoltaic capacity of 1 TW, exceeding the 590 GW goal for 2030 (Chatzipanagi et al., 2023). However, while agrivoltaics offers environmental and economic advantages, crop performance in shaded environments varies considerably, requiring focused study on species-specific responses (Elamri et al., 2018).

Hortivoltaics and its role in sustainable horticulture

Strawberry (*Fragaria × ananassa*) production is particularly sensitive to microclimatic variations, including temperature extremes, excessive solar radiation, and water scarcity

(Gommers et al., 2013). Integrating semi-transparent PV panels can mitigate heat stress, reduce evapotranspiration, and improve water-use efficiency (Valle et al., 2017). Yet, shading intensity and light spectrum alterations influence critical fruit quality parameters such as sugar accumulation (Brix), fruit firmness, and overall yield (Dupraz et al., 2011). The ability of strawberries to adapt to shaded environments is an area of ongoing investigation, with some studies suggesting that moderate shading may enhance fruit quality while excessive shade reduces yield (Marrou et al., 2013; Weselek et al., 2021)

This study evaluates the impact of semi-transparent PV panels on strawberry (*Fragaria* × *ananassa* ‘Sibilla’) cultivation in Southeastern Romania, focusing on microclimatic modifications, water efficiency, and fruit quality parameters. Conducted at the Moara Domnească Experimental Base, the research compares two semi-transparent photovoltaic (PVST) panel types - PV1 (48.92% transparency) and PV2 (77.01% transparency) - against an open-field control. Microclimate monitoring encompasses air and soil temperatures, soil moisture, and relative humidity, addressing the dual role of photovoltaics as an energy source and a potential agricultural microclimate stabilizer.

Initial findings indicate that PV panels reduce air temperature fluctuations (5.30°C lower under PV vs. control), contribute to soil moisture conservation, and modify fruit development. While PV1 panels resulted in lower fruit weight and sugar content, PV2 panels maintained comparable sugar levels (30.33% Brix) and firmness (3.27N) to control conditions, suggesting that transparency level plays a pivotal role in optimizing strawberry growth.

Given the rising frequency of heatwaves and prolonged droughts, horticultural systems integrating semi-transparent photovoltaics may provide a sustainable solution to enhance crop resilience while supporting renewable energy goals. However, further research is required to establish optimal panel transparency, crop compatibility, and long-term yield implications. This study contributes to the growing body of knowledge on hortovoltaics as a climate adaptation strategy, offering insights into its

potential for scaling up sustainable strawberry production in Romania and beyond.

MATERIALS AND METHODS

In this article, we focus exclusively on hortovoltaic systems that utilise semi-transparent panels installed above strawberry crop, based on practical experience acquired from the design, integration, and implementation of the first two such systems in semi-open spaces in Romania in 2023.

There are multiple factors that are to be taken in to account when we describe the materials and methods used in our experiment.

1. Experimental site description

The research site, situated at approximately 44°30'14.85" latitude and 26°14'45.60" longitude, with an altitude of around 660 meters above sea level, is located within the premises of the Moara Domnească Experimental Base, which is part of the Research and Development Station for Fruit Tree Growing Baneasa. This base is situated in the Vlăsiei Plain, a subunit of the Romanian Plain, in Ilfov County, Romania, specifically in the northeastern outskirts of Bucharest (17 km from city center).

The area around Moara Domnească is characterized by a temperate-continental climate with an average annual temperature of 10.9°C. Summers are warm with an average July temperature of 22.9°C, while winters are cold with an average January temperature of -2.8°C. Extreme temperatures can range from -30°C in January to 41.1°C in August.

Precipitation averages 580 mm annually, with June receiving the most (92 mm) and February receiving the least (31 mm). This uneven distribution can lead to periods of excess humidity throughout the year. Interestingly, winter receives about 27% (or 564.1 mm) of the total annual precipitation. Overall climatic farm characterization is humid climate with hot summers and harsh winters and powerful wind. (Dogaru and Dragomir, 2021)

The dominant air circulation is from the East and North-East in winter and from the West in the rest of the year, with a maximum wind speed of 12.6-14.4 km/h. The zonal soil type is reddish luvisol. In the depressed areas and in

the crevices, there are reddish luvisols and stagnosols.

2. The hortivoltaic system design

The agrivoltaic/hortivoltaic system is composed by a mobile metal structure that supports semi-transparent photovoltaic panels (STPV) from Brite Solar, optimized to allow partial light penetration. This design reduces thermal stress on the crops and enhances energy efficiency.

The system was arranged with multiple rows of photovoltaic (STPV) panels, tailored to the specific dimensions of the strawberry crops (Figure 1) and the operational needs of agricultural machinery.



Figure 1. Hortivoltaic system above the strawberry rows

This configuration has been designed in an innovative way to support both electricity generation and favourable conditions for strawberry growth, serving as a concrete example of integrating green technologies into agriculture. The hortivoltaic system has the potential to improve crop productivity and quality under controlled environmental conditions.

Installed in June 2023, the system covers a total area of 0.0125 hectares, with an installed capacity of 9 kWp. It includes two types of semi-transparent photovoltaic (STPV) panels: PV1, with 48.92% transparency (model BSG-250/49-F [BR], 250 Wp), and PV2, with 77.01% transparency (model BSG-115/77-F [BR], 115 Wp) (Figure 2). An uncovered area serves as a control plot.

Microclimate monitoring was done using a system of data acquisition and control, SDAQ, composed by a Wireless Sensor Network, WSN, based on wireless sensor node, which includes different type of sensors, a

microcontroller, a communication module and a power source. The sensor network was designed to monitor atmospheric and soil parameters.



Figure 2. Hortivoltaic two types of semi-transparent photovoltaic panels

Soil parameters monitoring was done with Aranet sensors able to capture in real time moisture, temperature, nutrient level, plant condition, etc. Microclimate parameters were also monitored with *Aranet* sensors for air temperature and humidity at a height of 2 m above the ground.

To allow field maintenance activities using traditional land machinery, the sensors were positioned in the strawberry rows' non-processable area, level with the AV facility's steel columns. Soil sensors for the recording of soil moisture and temperature were placed next to the sampling areas and only installed during the period June to August 2023. All soil sensors were removed after October. Each parameter and treatment were averaged for statistical analysis. Data on rainfall, solar radiation, and temperature were obtained from the weather station (*Adcon Telemetry*) in order to compare the meteorological conditions.

3. Strawberry variety 'Sybilla'

In our experiment, the strawberry variety 'Sibilla' of *Fragaria x ananassa* was the topic of observations. This cultivar is distinguished by robust plants featuring deep green, lustrous foliage. The fruits are of medium to large size, with a conical or truncated conical form with a subtly tapering apex, having a vivid red hue, a smooth texture, sweet and robust flavour harmoniously balanced between sweetness and acidity, rendering them suitable for both fresh consumption and processing. The maturation phase starts in May-June, and the plants exhibit

significant resistance to foliar and root pathogens.

The plants were arranged in a double-row configuration per plot. Each plot measured 140 cm wide. Plant spacing within each row was 30 cm, while inter-row spacing was 70 cm. A 50 cm gap separated each plot. *Agrotextile* mulch was used for soil cover (Căliniță et al., 2022). Irrigation was delivered via a subsurface drip irrigation system comprised of two pipes.

The experimental design incorporated randomized blocks (Figure 3) with three replicates, each including three 2-meter zones on raised beds subjected to various treatments: PV1, PV2, and an uncovered Control. Six rows of strawberry plants spanning the entire length of both photovoltaic panel variants and continued beyond the covered area control group, oriented in a north-south direction were chosen for the experiment. To reduce the potential edge effects and the influence of shading on data collection, two central rows were used for specific measurements (atmospheric and soil temperature, relative humidity, soil moisture) and fruit sampling.

Fruit samples were gathered at three distinct periods, and biometric studies were performed on 20 samples at each interval. Biometric determinations were including fruit average weight (Precisa XT 620M balance), height and diameter (digital caliper), soluble solid content (°Brix), pH (Hanna Instruments pH meter HI 700630) and firmness (computerized penetrometer).



Figure 3. Experimental plots under Hortivoltaic system

Statistical analyses were carried out using Microsoft Excel and Duncan's test with a significance level of 0.05%.

RESULTS AND DISCUSSIONS

Microclimate change under semi-transparent photovoltaic panels

Variation in microclimate factors is one of the most vital issues for horticultural practices underneath semi-transparent photovoltaic panels (STPV) array. The reduction in solar radiation is the primary altered factor under the agri photovoltaic canopy (Cossu et al., 2020). However, several other microclimate factors, such as air temperature and humidity, may also be affected.

In our experiment, we observed the average air and soil temperatures across June, July, August, September, and October, along with corresponding relative humidity levels for both air and soil.

The Table 1, these values are presented alongside data for two specific metrics related to photovoltaic (STPV) panels with varying transparency levels, respectively PV1 - 48.92% transparency and PV2 - 77.01% transparency. An uncovered area, reference, serves as a control plot.

Table 1. Microclimatic data based on variants Moara Domnească, Experimental Base

Medium/ Month/Parameter	VI	VII	VIII	IX	X
<i>Average air temperature (2m), °C</i>					
Reference	21.48	25.40	25.88	21.76	15.39
PV1	16.47	20.10	20.07	16.55	10.27
PV2	18.18	22.40	22.68	18.36	12.29
<i>Average air relative humidity - % RH</i>					
Reference	68.30	60.80	69.20	67.00	56.00
PV1	72.05	64.15	73.50	71.68	59.58
PV2	70.52	62.40	71.60	69.25	57.82
<i>Average soil temperature (10 cm depth), °C</i>					
Reference	22.60	25.80	26.20	20.30	16.30
PV1	21.86	25.00	25.25	19.60	15.70
PV2	22.14	25.35	25.70	19.94	16.00
<i>Average soil relative humidity (10 cm depth), % RH</i>					
Reference	16.47	20.44	21.41	20.20	19.80
PV1	19.20	23.70	24.75	23.30	22.90
PV2	18.69	23.10	24.21	22.84	22.35

As can be observed in the Figure 4, the *air temperature* profiles recorded under the influence of photovoltaic systems, showed

noticeable variations compared to the uncovered conditions (21.98°C), compared with PV1 (16.29°C) and PV2 (18.38°C). This indicates a cooling effect associated with the shading provided by the less transparent photovoltaic panels PV1. The minimum temperatures were registered also under PV1 (10.27°C), while under PV2 (12.29°C). These minimum values are much lower than the minimum reached in the reference area (15.39°C). Regarding the maximum temperatures, we have observed a direct relation between the level of transparency and recorded values, respectively: PV1 (20.10°C), PV2 (22.68°C), and the reference (25.88°C). The thermal range, representing the difference between maximum and minimum temperatures, was slightly narrower in the PV treatments (9.83°C for PV1 and 10.39°C for PV2) compared to the reference (10.49°C), suggesting a moderating effect on temperature fluctuations due to the photovoltaic structures.

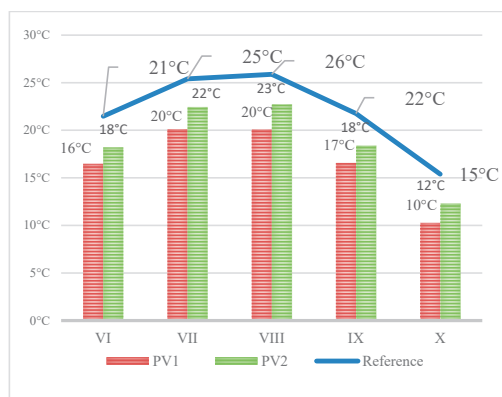


Figure 4. Average air temperature (height 2 m), °C

Regarding air relative humidity (Figure 5), it is to be taken in to consideration that the hortivoltaic system is a semi-open structure, with no barriers that can obstruct air circulation. Thus, air relative humidity may be affected. Nevertheless, under the two semi-transparent photovoltaic panels, the relative humidity values recorded notable differences compared to the reference conditions. The average relative humidity in the reference area was 64.26%, while under PV1 value was 68.19% and under PV2 66.32%. The higher humidity value indicates that the shading effect of STPV reduces evapotranspiration and helps

retain moisture in the microclimate. Maximum air relative humidity was recorded under PV1 (73.5%) and PV2 (71.6%), compared to 69.2% in the reference.

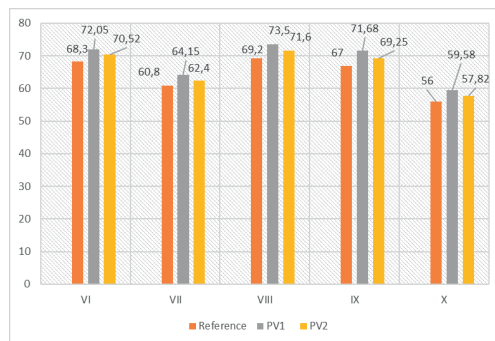


Figure 5. Average air relative humidity (%) under STPV and reference

With respect to the *soil temperature* influenced by PVST and measured at 10 cm depth, it has been observed similar trends to the other two factors analysed before. Under PV1 the soil temperature ranged between 15.70°C and 25.25°C, under PV2 - 16.00-25.70°C and the reference area was recording slighter higher values compared to the variants, respectively 16.30°C to 26.20°C. Regarding the maximum and minimum soil temperature, it is to be observed that the semi-transparent photovoltaic panels have an marginal influence, the STPV moderating this factor, particularly during peak temperature intervals. The warmest day, the uncovered soil has reached 26.20°C, while the soil under PV1 and PV2, the values remained slightly reduced at 25.25°C and 25.70°C, respectively. These data suggest that the the photovoltaic panels are having a buffering effect on soil temperature, with the potentially for reducing thermal plant stress and with positive effect on improving moisture conservation in the root zone. Both, soil humidity and temperature could influence various factors like plant growth, microbial activity, and overall soil health. Further research is necessary to explore these potential effects in detail.

Regarding the average soil humidity, our finding confirms the previous studies (Marrou, Dufour and Wery, 2013) that reported increased soil moisture under agrivoltaic due to

reduced evapotranspiration. This research, however, was mostly concerned with spring vegetables like cucumber, lettuce, and also maize grown in irrigated systems. Our study refers to the microclimate under hortivoltaic system, semi-transparent photovoltaic panels (STPV) with different transparency levels. When compared to uncovered control areas, our data reveals a significant drop in soil and air temperatures beneath STPV panels

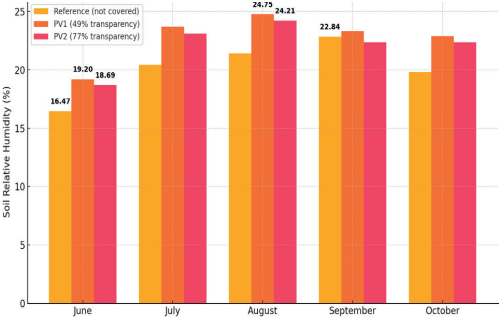


Figure 6. Average soil relative humidity (%) under STPV and reference

As shown in the graph Figure 6, higher mean soil moisture has been recorded under STPV panels compared to the reference. The variant PV1 with a value of 22.77%, is followed by PV2 with 22.24%, while the reference plot had a lower average of 19.66%. If we consider the maximum and minimum levels of soil moisture, the minimum values were reached in June under PV1 at 19.20%, PV2 at 18.69%, and reference plots registered a minimum of 16.47%. Concerning maximum relative humidity, the highest soil moisture content was observed in July, PV1 (24.75%) and PV2 (24.21%), but the reference plot recorded 21.41% during the same period. This peak may be attributed to seasonal factors such as increased rainfall or irrigation during the summer months. As it can be observed in the Figure 6 there is a consistent increase in soil moisture from June to July, followed by a slight decrease towards September. The PV systems maintained higher moisture levels throughout the growing season compared to the reference plot.

Effect of STPV panels on fruit characteristics
During 2023-2024 the fruit characteristics were observed regarding biometric and qualitative

parameters. The collected indicators include average weight, fruit height and diameter, soluble solid content (Brix), pH, and firmness. The Table 2 presents the influence of semi-transparent photovoltaic panel coverage on selected biometric and qualitative traits of strawberry fruit. The dataset compares three experimental variants: PV1 (48.92% transparency), PV2 (77.01% transparency), and a reference (uncovered) control.

Table 2. Fruit characteristics under hortivoltaic system

Variant	Average fruit weight (g)	Sugar (Brix)	pH	Fruit firmness (kgf)
PV1	15.46	7.20	3.52	3.27
PV2	15.25	7.90	3.51	3.15
Reference	19.49	8.60	3.64	3.08

The collected data highlighted significant effects of light modulation on fruit development and compositional parameters. Regarding, the **average fruit weight** it was observed that in PV1 as well as in PV2 the values were lower than the reference. So, under PV1 the average fruit weight was 15.46 g while under PV2 15.25 g, respectively, compared to 19.49 g in the reference area. Figure 7 illustrates the variations in average fruit weight across the experimental treatments, highlighting the effect of photovoltaic panel transparency on strawberry biomass accumulation.

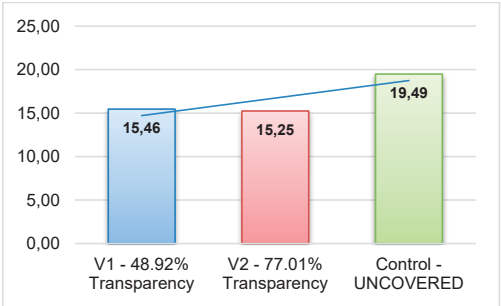


Figure 7. Average fruit weight under STPV and reference

The high differences suggest that the reduction in available solar radiation, particularly under the lower-transparency PV1 panels, had a more pronounced inhibitory effect on fruit growth.

This is likely attributable to diminished photosynthetic activity, which in turn affects carbohydrate accumulation and sink development. The shade effect had significant effect on fruit weight reducing it if we compare to the fruits from control area. This indicates that any level of artificial shading may constrain productivity in strawberry cultivation to some extent.

The soluble solids content (SSC, °Brix), a key quality index in pomological evaluation, followed a similar decreasing trend under shading, with values of 7.20 (PV1) and 7.90 (PV2) compared to 8.60 in the reference area. This reflects a possible delay in sugar accumulation processes, commonly associated with lower light intensity and cooler microclimates under photovoltaic coverage. Interestingly, fruit firmness, a determinant of postharvest behaviour and market value - was enhanced under the PV systems, reaching 3.27 kgf in PV1 and 3.15 kgf in PV2, surpassing the control (3.08 kgf). Figure 8 shows the effect of semi-transparent photovoltaic panels over the fruit firmness.

This increase may be attributed to a moderated ripening rate and reduced transpiration under shaded conditions, which contributes to denser tissue structure.

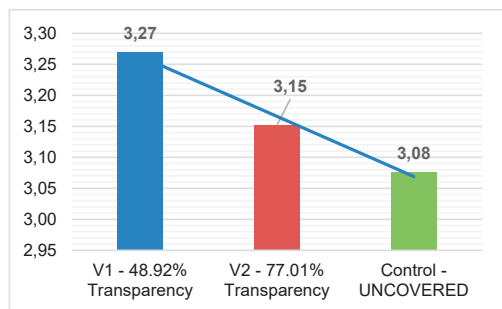


Figure 8. Average fruit firmness under STPV and reference

The **fruit pH** showed minor yet consistent reductions in PV treatments (3.52 and 3.51), suggesting a slightly higher titratable acidity under shaded environments, which may influence both organoleptic properties and shelf stability.

From a pomological perspective, the study is revealing complex interactions between light and fruit quality traits. Reduced solar radiation

under PV panels may constrain certain yield-related characteristics such as fruit size and sugar concentration it can simultaneously enhance attributes like firmness, which are critical for transport and storage.

Impact of semi-transparent photovoltaic panels on microclimate and its correlation with fruit qualitative characteristics

Reduced air temperature and lower average fruit weight

The reduction in air temperature observed under semi-transparent photovoltaic (STPV) panels, particularly in the PV1 variant (16.29°C) compared to the uncovered control (21.98°C), had a direct influence on the growth dynamics and fruit development of strawberries. Cooler air conditions are known to slow down plant metabolic activity and biomass accumulation, which likely explains the lower average fruit weight recorded under PV1 (15.46 g) and PV2 (15.25 g) compared to the control (19.49 g). This outcome suggests a strong correlation between light availability, ambient temperature, and fruit biomass formation.

Decreased solar radiation and lower sugar content (Brix)

The soluble solids content (expressed in °Brix), is an indicator of fruit sweetness, The value of sugar content was significantly lower in the shaded variants - 7.20 in PV1 and 7.90 in PV2 - compared to 8.60 in the control. This drop can be attributed to a dropped photosynthetic exertion under limited solar radiation, leading to lower sugar accumulation in the fruits. therefore, the cooler and shadier microclimate beneath the STPV systems results in fruits with lower agreeableness, a quality parameter directly told by light interception.

Air humidity and fruit firmness

Interestingly, despite producing lower and lower sweet fruits, the shops grown under STPV panels yielded firmer strawberries, with values of 3.27 kgf under PV1, compared to 3.08 kgf in the control. This increase in firmness may be linked to the advanced relative air moisture observed beneath the panels (PV1 68.19, control 64.26). Humid soils can reduce plant water stress and evapotranspiration,

decelerating down fruit growing processes and thereby enhancing fruit texture and firmness.

Soil temperature and moisture – synergistic effects on quality

The cooler and more humid soil environment under the STPV panels (PV1 outside soil temperature 25.25°C vs. 26.20°C in the control; average soil humidity 22.77 in PV1 vs. 19.66 in the control) contributed to maintaining a more favourable hydric balance in the root zone. This medium supports a nonstop force of water and nutrients to the factory, which may enhance

fruit firmness and post-harvest eventuality. also, increased soil humidity can stimulate salutary microbial exertion in the rhizosphere, laterally perfecting nutrient vacuity and factory health.

Table 3 shows the overall fruit characteristics in relation with microclimatic conditions. The data indicate that semi-transparent photovoltaic panels (PV1 and PV2) led to reduced air temperature and fruit weight, but increased soil moisture and fruit firmness compared to the uncovered reference.

Table 3. Combined microclimate and fruit quality indicators across STPV and reference treatments

Treatments/ parameters	Air temp. (°C)	Air RH (%)	Soil temp. (°C)	Soil RH (%)	Fruit weight (g)	Sugar (Brix)	pH	Firmness (kgf)
Reference	21.982	64.26	22.24	19.664	19.49	8.6	3.64	3.08
PV1	16.692	68.192	21.482	22.77	15.46	7.2	3.52	3.27
PV2	18.782	66.318	21.826	22.238	15.25	7.9	3.51	3.15

CONCLUSIONS

This research emphasizes the advantages and downsides of using semi-transparent photovoltaic (STPV) systems in strawberry growing. The objectification of STPV panels rounded in significant differences to the microclimatic conditions, including diminishments in air and soil temperature and elevations in relative moisture. These changes established a more softened and stable terrain, especially during peak temperature times, which might be profitable for easing factory stress and enhancing water retention in the root zone.

From fruit quality point of view, shade displayed both salutary and mischievous impacts. Reduced light vacuity identified with reduced fruit weight and sugar content, indicating a constraint in photosynthetic exertion and assimilate buildup. Again, the cooler and further sticky microclimate beneath the panels enhanced fruit firmness, a characteristic profitable for transportation, shelf life, and post-harvest quality.

The experiment identified obstacles from functional perspective, effect of semi-transparent photovoltaic panel shadowing intensity, the need for accurate microclimate monitoring, and the difficulty in coordinating

light conditions with energy generation. These factors emphasize the need of maximizing panel translucency and spatial arrangement to fulfil the physiological conditions of the crop while maintaining the system's energy effectiveness.

The study effectively established that the agricultural land can be used for fruit producing in the same time with electricity generation, having under STPV horticultural crop with high value. Also, the study has underlined the need for promotion of interdisciplinary cooperation between agrarian and energy exploration fields.

nevertheless, constraints such the limited observation duration, the attention on a single crop, and the lack of physiological assessments at the splint or factory position suggest that further exploration is necessary. unborn study need to probe colorful crop kinds, long-term goods, and profitable evaluations to enhance the assessment of the sustainability and scalability of STPV systems in horticulture.

The strawberry varieties selection for cultivation in the hortivoltaic systems should consider two main factors: tolerance to partial shading and avoidance of fast-maturing varieties. Varieties that can thrive in diffuse light conditions and develop their fruits during the summer will benefit the most from the

advantages of these innovative systems. This type of integration of agriculture with renewable energy not only optimizes the use of natural resources but also contributes to the sustainability of modern agriculture

Hortivoltaic systems can offer several advantages, including:

- increased crop yield, particularly for shade-tolerant or high-value horticultural crops;
- improved land-use efficiency through dual-purpose utilization - simultaneous food production and solar energy generation on the same surface;
- reduced water consumption, due to lower evapotranspiration rates, contributing to better water-use efficiency;
- dual use of water resources, with irrigation water also serving for PV panel maintenance and cleaning, enhancing operational sustainability;
- integration of sensors and smart technologies on PV structures to enable real-time crop and environmental monitoring, supporting precision horticulture;
- partial protection of crops against abiotic stressors such as UV-b radiation, extreme temperatures, wind, or hail, improving overall plant resilience and reducing losses.

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