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IMPACTUL PANOURILOR FOTOVOLTAICE SEMI-TRANSPARENTE ASUPRA CALITĂȚII CĂPȘUNILOR 'SIBILLA' ÎN SUD-ESTUL ROMÂNIEI

IMPACT OF SEMI-TRANSPARENT PHOTOVOLTAIC PANELS ON THE QUALITY OF 'SIBILLA' STRAWBERRY IN SOUTHEASTERN ROMANIA

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Abstract

Ongoing climate change and associated abiotic stress from high temperatures and intense light during the vegetative stages significantly impact the productivity and quality of strawberries (*Fragaria x ananassa*). These stresses can inhibit growth, reduce yields, and lower fruit quality, necessitating adaptive cultivation strategies. This study focuses on the use of hortivoltaic systems, which integrate electricity production with fruit cultivation, providing a shading effect that may benefit strawberry plants. As short-day plants, strawberries require 6-8 hours of direct sunlight to initiate flowering and fruiting; however, excessive light exposure, especially during peak hours, can induce stress, affecting physiological processes and reducing yield and quality. Shading techniques may, therefore, be advantageous in hot climates to alleviate these effects. The experiment took place at the Moara Domneasca Experimental Base on 'Sibilla' strawberry variety. A Hortivoltaic plant was installed in June 2023 with two variations of semi-transparent photovoltaic panels: PV1 with 48.92% transparency and PV2 with a higher 77.01% transparency. A reference area without any covering served as a control. The experimental setup consists of an open space with uncovered edges that is situated above the strawberry rows. Within this space, randomized blocks with three replicates were established for the purpose of conducting the measurements. After harvest, any damaged fruits were removed. To assess the impact of the shading variations, 20 randomly chosen marketable fruits from each area were evaluated for several quality parameters: weight, diameter, firmness, sugar content, and pH. Analysis of average fruit weight revealed the lowest value (15.46 g/fruit) under the PV1 panels with 48.92% transparency. Conversely, fruits from the uncovered reference area displayed a significantly higher average weight of 19.49 g/fruit. Interestingly, the PV2 panels with the highest transparency (77.01%) yielded fruit with comparable sugar content (30.33% Brix) to those grown in the uncovered area (33.76% Brix). This suggests minimal impact of PV2 shading on fruit sugar accumulation. Evaluation of fruit firmness demonstrated comparable values across all treatments. Average firmness ranged from 3.27 to 3.08N, indicating minimal influence of shading on this quality parameter. In summary, while the PV1 panels with lower transparency negatively impacted fruit weight as well as other qualitative parameters, the PV2 panels with higher transparency showed promising results in maintaining sugar content and firmness, highlighting the potential benefits of strategic shading in optimizing strawberry production under climatic stress conditions.

Cuvinte cheie: sistem hortivoltaic, căpșun, stres abiotic, umbrire, calitatea fructelor.
Key words hortivoltaic system, strawberry, abiotic stress, shading, fruit quality.

1. Introduction

As climate change intensifies and global food security becomes more critical, sustainable agriculture has gained significant focus. One promising approach is the integration of agrivoltaic systems, particularly in horticulture, termed "hortivoltaics." Agrivoltaics, a fusion of "agriculture" and "photovoltaics," enables simultaneous crop production and electricity generation on the same land. Originally conceptualized by Prof. Adolf Goetzberger and Dr. Armin Zastrow in 1982, this approach has evolved, with diverse methods now used to combine crops and photovoltaic panels, from non-transparent panels above crops to semi-transparent panels and covered greenhouses.

Agrivoltaic systems enhance land efficiency by optimizing sunlight, water, and soil use, benefiting crop yields, soil quality, and biodiversity. Bush crops, like strawberries, may benefit from hortivoltaic systems, as shading can mitigate heat stress, conserve soil moisture, and improve fruit quality. However, few studies examine bush crops' specific adaptations within these systems, highlighting a need for further research.

The Paris Agreement, aiming to limit global temperature rise, has accelerated renewable energy adoption. The European Commission sees agrivoltaics as key to surpassing EU photovoltaic targets for 2030, potentially achieving 1 TW capacity by using only 1% of agricultural land.

Despite benefits, there are challenges. Different crops respond uniquely to shade, impacting yield potential in agrivoltaic systems. For example, strawberries (Fragaria x ananassa), valued in Romania for their flavor and nutritional content, are adaptable but sensitive to shading. Understanding shade tolerance is essential for optimizing crop-panel combinations. This study investigates the impact of semi-transparent photovoltaic panels on 'Sibilla' strawberry quality in Southeastern Romania, providing insights into hortivoltaics' potential benefits and challenges for modern agriculture.

However, as highlighted by recent studies, the impact of agrivoltaics on horticultural crops like strawberries must be carefully considered. Understanding how different crops respond to shading and the extent of shade they can tolerate without significant yield loss is crucial for determining successful crop-panel combinations. While differences in shade tolerance among plant species are recognized, the specific qualitative impacts on crop performance remain a key area for further exploration. This study aims to investigate the impact of semi-transparent photovoltaic panels on the quality of 'Sibilla' strawberries in Southeastern Romania, providing insights into the potential benefits and challenges of integrating this technology into modern agricultural practice.

2. Material and methods

2.1. Context

During 2023-2024, at the Moara Domnească Experimental Base, located 25 km from Bucharest, an innovative model for strawberry cultivation was established and tested using an advanced hortivoltaic system. This experimental base, situated at coordinates 44°30'14.85" latitude and 26°14'45.60" longitude, serves as a research platform for exploring sustainable technological solutions in agriculture.

2.2. Climatic conditions of the study area

The Southeastern region of Romania has a temperate-continental climate, with an average annual temperature of 10.9°C. The average temperature in January is -2.8°C, while in July, it reaches 22.9°C. Extreme temperature values vary between 41.1°C in August and -30°C in January. The average annual precipitation is 580 mm, with the highest monthly average occurring in June (92 mm) and the lowest in February (31 mm). Excess humidity can occur due to the uneven distribution of rainfall during certain periods of the year, as well as from annual variations.

The average precipitation in the Moara Domnească area is 564.1 mm, with 27% of the annual total recorded during the winter season.

2.3. In the experiment strawberry *Fragaria x ananassa* variety 'Sibilla' was planted. This variety is characterized by vigorous plants with deep green, glossy leaves. The fruits are medium to large, featuring a conical or truncated conical shape with a slightly tapered tip. They exhibit a bright red color, smooth texture, and a sweet, intense flavor that is perfectly balanced between sweetness and acidity, making them ideal for fresh consumption or processing. The ripening period begins in May-June, and the plants are highly resistant to leaf and root diseases. In this cultivation system, the plants are arranged in two rows on raised beds covered with agrotextile, with a spacing of 30 cm between plants and 70 cm between beds, and the system is equipped with drip irrigation for efficient water management.

2.4. The hortivoltaic system (Fig. 1 and Fig.2) includes a mobile metal structure that supports semi-transparent photovoltaic panels from Brite Solar, optimized to allow partial light penetration. This design reduces thermal stress on the crops and enhances energy efficiency.

The system is arranged with multiple rows of photovoltaic (PV) panels, tailored to the specific dimensions of the strawberry crops and the operational needs of agricultural machinery. This configuration ensures both electricity generation and favorable conditions for strawberry growth, serving as a concrete example of integrating green technologies into agriculture. It 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 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). An uncovered area serves as a control plot.

The experimental design, involved randomized blocks with three replicates, each containing three 2-meter zones on raised beds covered with different treatments: PV1, PV2, and an uncovered Control. Fruit samples were collected at three different intervals, and biometric analyses were conducted on 20-fruit samples each time. The determinations included measuring the average weight using a Precisa XT 620M balance, assessing fruit height and diameter with a digital caliper to calculate the size index, evaluating soluble solid content (°Brix), and measuring pH with a Hanna Instruments pH meter (model HI 700630). Firmness was assessed using a digital penetrometer.

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

3. Results and discussions

Table 1 presents impact of photovoltaic panels on the biometric and qualitative characteristics of strawberries by comparing the three experimental treatments (PV1, PV2, and the uncovered control). The collected indicators include average weight, fruit height and diameter, soluble solid content (Brix), pH, and firmness.

3.1. Influence of semi-transparent photovoltaic panels on average fruit weight

Determinations on average fruit weight are shown in the Fig. 2. As it can be observed the graph indicates a significant influence of photovoltaic panel transparency on the average weight of strawberries. In the PV1 variant, with 48.92% transparency, the average fruit weight was 15.46 g, compared to 15.25 g in the higher transparency PV2 variant (77.01%). These values are notably lower than those in the uncovered control area, where the average fruit weight reached 19.49 g.

These differences suggest that reduced sunlight availability, especially in the lower-transparency PV1 panels, had a more pronounced negative impact on fruit growth, likely due to limitations in photosynthesis. Even with the higher-transparency PV2 panels, fruit weights did not reach those of the control, indicating that shading from the panels negatively affects production.

Throughout the three harvests, fruit weight showed an overall decline, particularly after the first harvest, potentially due to unfavorable climatic conditions or other biotic and abiotic factors.

3.2. Influence of semi-transparent photovoltaic panels on fruit soluble sugar content

The graph (Fig. 4) compares the soluble sugar content (°Brix) of strawberries under the three experimental treatments: uncovered control, PV2, and PV1. The uncovered control obtained the highest average sugar concentration at 8.60 °Brix, suggesting that unshaded conditions promote optimal photosynthesis and efficient carbohydrate accumulation, resulting in a higher sugar content. In the PV2 variant, with 77.01% transparency, fruits recorded a slightly lower average of 7.90 °Brix. While this value is lower than the control, the reduction in sugar content is less pronounced, indicating that the higher transparency of PV2 panels allows sufficient light to support relatively high sugar levels.

In contrast, the PV1 variant, with a lower transparency of 48.92%, showed the lowest soluble sugar content at 7.20 °Brix. This reduction reflects the limited light penetration, which negatively affects photosynthesis and leads to a decrease in sugar accumulation in the fruits. The maximum value of 8.60 °Brix in the control area confirms that direct sunlight exposure enhances sugar buildup in fruits. The gradual decrease in sugar content in PV2 and PV1 suggests that shading from photovoltaic panels impacts sugar production, with a more pronounced effect in PV1 due to reduced transparency.

Statistically, according to the Post Hoc Tukey test, significant differences were observed between V1 and V2, while very significant differences were found between V1 and the control, as well as between V2 and the control, across individual harvests. These results highlight the importance of optimizing shading levels to balance energy production with fruit quality.

3.3. Influence of semi-transparent photovoltaic panels on the fruit firmness

The determinations showed (Fig. 5) that varying levels of photovoltaic panel transparency influenced this parameter to some extent. Fruits grown under the V1 treatment, with lower transparency (48.92%), exhibited the highest firmness at an average of 3.27 kgf. This increase in firmness suggests that reduced sunlight may contribute to a slower growth rate or structural changes in the fruit. In the V2 treatment, with higher transparency (77.01%), the average firmness was slightly lower at 3.15 kgf, indicating a balanced influence of filtered sunlight. Meanwhile, fruits from the uncovered control area showed the lowest firmness, averaging 3.08 kgf, likely due to faster ripening under full sunlight. These results suggest a trend where increased shading from photovoltaic panels may lead to slightly firmer fruits, though overall differences across treatments were minimal, pointing to a limited impact of panel shading on fruit firmness

In conclusion, regarding the impact of photovoltaic panels on fruit quality indicators, the PV1 panels, with lower transparency, had a negative effect on fruit weight and quality, impairing photosynthesis and sugar production, resulting in smaller and lower-quality fruits. Parameters such as soluble sugar content and pH were also negatively impacted.

On the other hand, the PV2 panels, with higher transparency, showed promising results in maintaining good fruit quality, suggesting that an adequate amount of sunlight, even when filtered, can support quality strawberry production. These panels could offer significant benefits by balancing shading and energy generation without significantly compromising fruit quality.

4. Conclusions

The results of our experiment highlight a variable influence of semi-transparent photovoltaic panels on the growth and quality of strawberries cultivated under agrivoltaic and hortivoltaic systems.

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.

Impact of the panels: The PV2 panels, with higher transparency, demonstrated promising results regarding fruit quality. This suggests that a filtered amount of solar light can support high-quality strawberry production while providing both shade and energy.

Recommendations: Continued research on optimizing the transparency of photovoltaic panels for various fruit crops and expanding the experiment to other plant species could enhance integrated hortivoltaic systems. By refining these systems, we can better balance agricultural productivity and renewable energy generation, fostering sustainable practices in horticulture

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Tables and figures

Fig. 1 Hortivoltaic system overview, panels and control structure

Fig. 2. Experimental plots and fruits under Hortivoltaic system

Table 1. Impact of photovoltaic panels on biometric and qualitative characteristics of strawberries

Variant	Average fruit weight (g)	Sugar (Brix)	pH	Fruit firmness (kgf)
V1 - 48.92% transparency	15,46	7,20	3,52	3,27
V2 - 77.01% transparency	15,25	7,90	3,51	3,15
Control - uncovered	19,49	8,60	3,64	3,08

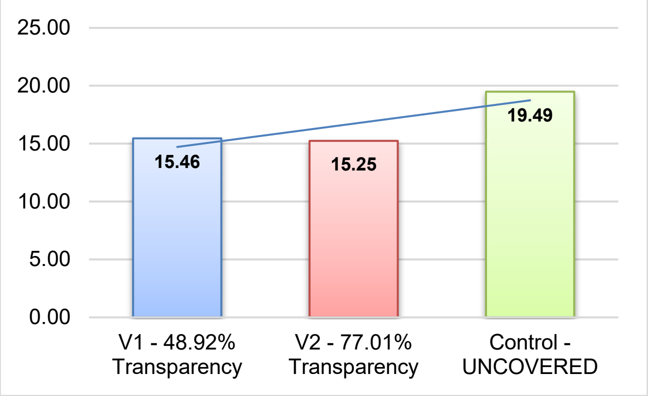

Fig. 3. Effect of photovoltaic panel transparency on the average weight (g) of 'Sibilla' strawberry fruits.

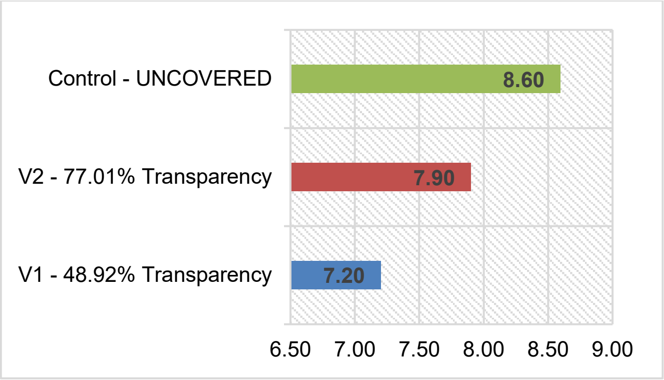

Fig. 4. Effect of photovoltaic panel transparency on the sugar content (Brix) of 'Sibilla' strawberry fruits"

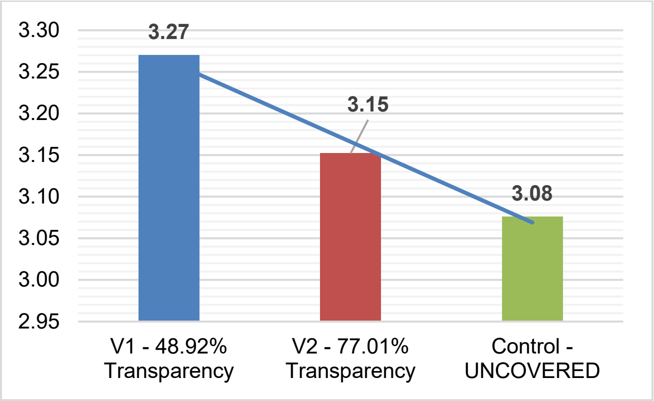

Fig. 5. Effect of photovoltaic panel transparency on the firmness of 'Sibilla' strawberry fruits