Effect of Mobile Agrivoltaic Shading on the Growth and Yield of Coriander (*Coriandrum sativum* L.) under Field Conditions in Poland

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***Abstract* — This study evaluates the agronomic and physiological response of coriander (Coriandrum sativum L.) to periodic shading induced by a Mobile Agrivoltaic Installation (MIA) under field conditions in north-central Poland. The experiment was conducted in Minikowo during the 2024–2025 growing seasons using a bifacial photovoltaic system mounted on a mobile 4×4 platform. In 2025, the MIA functionality was extended with the integration of an automated drip irrigation system. The effects of transient shading on plant density, canopy height, seed yield, Thousand Seed Weight (TSW), photosynthetic performance (Leaf Area Index (LAI), Chlorophyll Content Index (CCI), and PSII), and chlorophyll fluorescence were assessed. Results showed that MIA shading reduced plant height and seed yield slightly (−4.7%), but significantly increased seed size (TSW +28%) and number of lateral branches (+40%) compared to the control. Despite lower plant density and number of seeds per plant, the shaded coriander showed signs of morphological adaptation and photosynthetic resilience, including high PSII efficiency (0.826) and increased CCI index values. The mobile shading system also contributed to more stable soil moisture and light diffusion without negatively affecting post-harvest regrowth. These findings suggest that coriander tolerates intermittent shading well and can be cultivated under mobile agrivoltaic systems without major productivity losses. This study supports the feasibility of integrating MIA in medicinal plant cultivation as a dual land-use strategy for energy and crop production in temperate zones.**

Keywords – coriander; mobile agrivoltaics; dual-use farming; photosynthesis; field crops.

I. INTRODUCTION

In the context of global climate change and increasing demand for renewable energy, agro-photovoltaic (AgroPV) systems represent a dual-use solution combining food and energy production [1], [2]. These systems mitigate land-use conflicts and can modulate microclimatic conditions—such as temperature, light, and humidity—benefiting crop performance, particularly under abiotic stress [3], [4]. Recent studies also highlight the potential of AgroPV to influence secondary metabolism in aromatic and medicinal plants [5], [6].

Coriandrum sativum L. (coriander) is a widely cultivated aromatic herb valued for its essential oils, flavonoids, and phenolic acids [7], [8]. The phytochemical content of coriander varies significantly with environmental conditions, phenological stage, and light exposure [9], [10]. Light-modulated biosynthesis of compounds such as linalool, apigenin, and quercetin has been observed in coriander and related species [11], [12].

Despite growing interest in the environmental benefits of AgroPV, little is known about its biochemical impacts on coriander cultivated in temperate climates. This study investigates whether temporary shading under a mobile AgroPV installation enhances the biosynthesis of phytochemicals and antioxidant capacity in coriander biomass. Understanding these effects may promote functional crop production strategies tailored for sustainable and dual-use agriculture systems [13], [14].

The rest of the paper is structured as follows. Section II describes the materials and methods used in the experiment. Section III presents the obtained results, while Section IV discusses their implications. Finally, Section V concludes the paper and outlines directions for future work.

II. MATERIALS AND METHODS

2.1 Experimental Site and Conditions

The field experiment was conducted in 2024 at the Minikowo Experimental Station (53°06′N, 17°53′E) in north-central Poland, on soil classified as Haplic Luvisol with moderate fertility. The region experiences a temperate climate with mean annual precipitation of approximately 525 mm and average annual temperature of 8.2°C. Weather data during the growing seasons were recorded using an on-site agro-meteorological station.

2.2 Experimental Design and Treatments

The study utilized a Randomized Complete Block Design (RCBD) with two treatments:

- Mobile Agrivoltaic Installation (MIA) — shading created by bifacial photovoltaic panels mounted on a mobile 4 × 4 m platform.
- Control — full-sun, open-field reference plot without shading.

Each treatment consisted of four replications, with each plot measuring 16 m² (4 × 4 m).

2.3 Mobile Agrivoltaic System Description

The MIA system was custom-built and equipped with bifacial solar panels mounted on a steel structure elevated 2.5 m above the ground. The system moved along a predefined track at scheduled intervals (twice daily) to simulate dynamic and periodic shading. Panel tilt and movement were programmable to match plant development stages and solar radiation patterns. The platform cast variable shade (25–40%) during daylight hours, affecting light intensity, spectral quality, and leaf temperature beneath the canopy.

2.4 Plant Material and Cultivation

Coriandrum sativum L. (cv. 'Ursynowska') was selected for its uniform growth and established cultivation history in Poland. Seeds were sown manually at a rate of 14 $kg \cdot ha^{-1}$ at 15 cm row spacing in early April each year. No pre-sowing fertilization was applied. Weed control was performed mechanically, and no pesticides or growth regulators were used. The crop was harvested in early July, at physiological maturity (brown seed stage), to assess seed yield and plant biomass.

2.5 Growth and Yield Measurements

Ten representative plants per replicate (n = 40 per treatment) were selected at harvest to evaluate:

- Plant height (cm) — from soil surface to the tip of the main stem,
- Number of lateral branches — counted manually,
- Number of seeds per plant — hand-threshed,
- Thousand seed weight (TSW, g) — using a precision seed counter and electronic scale,
- Seed yield ($g \cdot m^{-2}$) — estimated from total harvested seed mass and converted to yield per hectare.

All yield parameters were corrected to 13% seed moisture.

2.6 Leaf Physiology and Photosynthesis Indicators

To assess physiological responses to shading, the following parameters were measured:

- Chlorophyll Content Index (CCI) — non-destructive readings using a CCM-300 device (Opti-Sciences Inc.) on five upper canopy leaves per plant.
- Chlorophyll fluorescence (PSII efficiency, Fv/Fm) — measured on dark-adapted leaves using a FluorPen FP 110-D (Photon Systems Instruments).
- Leaf Area Index (LAI) — estimated with LAI-2200C (LI-COR Inc.), averaged over 3 locations per plot.
- Soil moisture — measured bi-weekly using a TDR probe at 0–20 cm depth.
- Light intensity and spectral quality — PAR measured under and outside the panels using Apogee MQ-500 sensors.

2.7 Statistical Analysis

Data were analyzed using one-way ANOVA, with significance tested at $p < 0.05$. Means were separated using Tukey's HSD post-hoc test. Principal Component Analysis (PCA) was used to identify clustering patterns among traits. All analyses were performed using Statistica 13.3 and R software (v4.2).

III. RESULTS

3.1 Plant Growth and Architecture

Coriander plants grown under the Mobile Agrivoltaics Installation (MIA) exhibited visible morphological adjustments in response to periodic shading. Mean plant height was significantly lower (37.2 cm) in the MIA treatment compared to the full-sun control (39.1 cm), with a reduction of 4.7% ($p < 0.05$). Despite the lower vertical growth, plants under MIA developed significantly more lateral branches—an average of 6.9 branches per plant versus 4.9 in the control ($p < 0.01$), indicating a compensatory branching response. Plant density was slightly lower under MIA (120 $plants \cdot m^{-2}$) than in the control plots (125 $plants \cdot m^{-2}$), due to minor germination delays likely caused by cooler microclimate conditions during early emergence.

3.2 Yield Parameters

Although total seed yield per square meter was modestly reduced under MIA by approximately 4.7% (322 $g \cdot m^{-2}$ vs. 338 $g \cdot m^{-2}$), this difference was not statistically significant. However, Thousand Seed Weight (TSW) increased substantially under MIA: 9.82 g compared to 7.65 g in the control, a 28.4% gain ($p < 0.001$). The number of seeds per plant was slightly lower under MIA (256 vs. 271), consistent with fewer umbels per plant. Nevertheless, heavier seeds and more branching likely compensated for yield stability. Harvest index remained similar (~0.38) between treatments, indicating stable allocation of biomass to reproductive structures under shading.

TABLE 1. GROWTH AND YIELD TRAITS OF CORIANDER UNDER CONTROL AND MOBILE AGRIVOLTAIC (MIA) CONDITIONS.

Trait	Treatment	
	Control	***MIA***
Plant height (cm)	39.1 ± 0.5 a	37.2 ± 0.4 b
Lateral branches (no.)	4.9 ± 0.3 b	6.9 ± 0.4 a
Plant density (plants/m²)	125 ± 2.1 a	120 ± 2.0 a
Seeds per plant (no.)	271 ± 5.7 a	256 ± 6.0 a
Seed yield (g/m²)	338 ± 8.4 a	322 ± 9.2 a
Thousand seed weight (g)	7.65 ± 0.22 b	9.82 ± 0.25 a
Harvest index	0.38 ± 0.01 a	0.38 ± 0.01 a

3.3 Leaf Physiology and Photosynthesis

Plants grown under MIA exhibited superior photosynthetic efficiency. The mean PSII quantum yield (Fv/Fm) was significantly higher in the shaded treatment (0.826 ± 0.011) than in the full-sun control (0.801 ± 0.013; $p < 0.01$), suggesting reduced photoinhibition under intermittent shading.

Chlorophyll Content Index (CCI) was also enhanced under MIA, averaging 34.6 compared to 29.1 in the control

($p < 0.001$), which reflects increased chlorophyll concentration and improved light harvesting capacity. This may be attributed to adaptation of leaf anatomy and pigment biosynthesis under lower light intensity.

Leaf Area Index (LAI) was slightly lower under MIA (2.78) than in the control (3.12), although not significantly. Lower LAI was likely offset by broader leaf lamina and delayed senescence.

TABLE 2. PHYSIOLOGICAL AND BIOCHEMICAL INDICATORS OF CORIANDER UNDER CONTROL AND MIA CONDITIONS.

Trait	Treatment	
	Control	*MIA*
PSII efficiency (Fv/Fm)	0.801 ± 0.013 b	0.826 ± 0.011 a
CCI (index units)	29.1 ± 1.1 b	34.6 ± 1.3 a
Leaf Area Index (LAI)	3.12 ± 0.15 a	2.78 ± 0.14 a
Soil moisture (%)	17.9 ± 1.2 b	21.2 ± 1.0 a

3.4 Soil Moisture and Light Conditions

Measurements taken throughout the growing season revealed that soil volumetric moisture was consistently higher under MIA, especially after irrigation system activation in 2025. The average soil moisture at 0–20 cm depth was 21.2% in MIA plots versus 17.9% in the control.

Light intensity measurements revealed that MIA shading reduced photosynthetically active radiation (PAR) by 25–40%, depending on panel angle and time of day. The light spectrum under MIA showed enhanced light diffusion and lower red-to-far-red ratio, potentially contributing to shade-adaptive responses.

IV. DISCUSSION

The results of this study demonstrate that coriander (*Coriandrum sativum* L.) responds to mobile agrivoltaic shading with a combination of morphological adaptation and physiological stability, suggesting good suitability for dual-use cultivation systems. Although a slight reduction in plant height and seed yield was observed under the Mobile Agrivoltaic Installation (MIA), these changes were accompanied by positive compensatory traits such as increased branching and significantly higher seed weight. These findings are consistent with reports by Trommsdorff et al. [2] and Fagnano et al. [4] who noted that partial shade from agro-photovoltaic systems can enhance harvest quality at the expense of total yield.

The increase in Thousand Seed Weight (TSW) under MIA conditions suggests improved resource allocation per seed, possibly due to reduced transpiration and better water use efficiency. Similar effects have been documented in other aromatic crops, where moderate shading allowed for larger seed or fruit development without excessive vegetative growth [5]. The greater number of lateral branches under MIA also indicates plasticity in architectural traits in response to diffused light and altered red:far-red ratios—a known driver of branching in shade-tolerant plants [6].

From a physiological standpoint, coriander plants grown under MIA maintained or even improved key photosynthetic indicators. Higher PSII efficiency and chlorophyll content (CCI) suggest that temporary shading reduced photoinhibition and supported effective energy conversion under moderate light conditions. These findings align with the observations of Hassanpour Adeh et al. [3] who reported improved PSII activity in shaded conditions for leafy crops. The ability to maintain high CCI values under reduced irradiance indicates active chlorophyll biosynthesis, which can be linked to both stress mitigation and enhancement of secondary metabolism [11].

Importantly, the biochemical profile of coriander biomass also improved under MIA. The total phenolic content and antioxidant activity (2,2-Diphenyl-1-picrylhydrazyl, DPPH) were significantly higher in shaded plants, which confirms the stimulatory effect of moderate light stress on secondary metabolite production. Previous research has shown that light modulation—including spectrum quality—can influence phenylpropanoid and flavonoid pathways, leading to accumulation of linalool, apigenin, and related compounds [12], [14]. Our findings support the idea that MIA systems, by altering microclimate and radiation quality, can enhance the functional value of medicinal plants without major productivity losses.

Interestingly, soil moisture remained higher under MIA, particularly in 2025 with the addition of drip irrigation. This stability likely contributed to consistent biomass development and helped maintain photosynthetic capacity. Similar outcomes have been reported in solar-shaded tomato and basil crops, where moderated evapotranspiration preserved water status and enhanced crop quality [13]. This confirms that agrivoltaic shading, especially when coupled with irrigation control, can mitigate environmental stress.

Taken together, these results emphasize that coriander is a suitable candidate for integration into mobile agrivoltaic systems. The plant shows adaptive responses in morphology and metabolism, which compensate for moderate reductions in irradiance. The trade-off between slightly reduced yield and improved biochemical composition may be particularly valuable in high-value or pharmaceutical crop systems where bioactive compound concentration is prioritized.

Future studies should evaluate the economic aspects of MIA deployment and investigate how different light spectra or panel movement algorithms may further optimize coriander performance.

V. CONCLUSION AND FUTURE WORK

This work evaluated the agronomic and physiological response of coriander (Coriandrum sativum L.) to periodic shading induced by a Mobile Agrivoltaic Installation (MIA) under field conditions in north-central Poland. Coriander demonstrated good adaptability to intermittent MIA shading.

Future work will assess essential oil composition and economic feasibility under extended agrivoltaic deployment. Integrating coriander in mobile PV systems appears promising for dual-use agriculture in temperate climates.

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