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THE EFFECT OF PHOTOVOLTAIC SYSTEMS ON BERRIES PRODUCTION. A REVIEW

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Abstract

Presently, there is a growing interest in berry production, particularly in developing innovative and resilient agricultural practices that align with consumer expectations for superior flavors and nutritional value. The yielding and quality of berries fruits are influenced by various abiotic and biotic stress factors, and closely monitoring of these can lead to significant improvements regarding production and fruit quality. Photovoltaic systems provide an innovative approach to improving the use of natural and anthropic resources, reducing the negative impacts of climate change, and enhancing environmental protection. In recent years, various studies have recognized the important benefits of photovoltaic systems in fruit production such as – reducing energy costs, decreasing carbon emissions at the farm level, preserving water resources, offer shelter for beneficial organisms, and improve fruit quality in terms of appearance and nutritional matter. This study aims to provide an extensive review of the current knowledge on the opportunities and advantages of photovoltaic systems for berry crops, with a particular focus on red currants. It explores their role in optimizing growth and fruiting, enhancing resource efficiency, and reducing abiotic stress – such as sunburn for example.

Key words: *abiotic stress factors, innovative cropping systems, red currant, resilient agriculture, sustainable farming.*

INTRODUCTION

Recent studies indicate a growing interest in berry production (Aguilera, 2024; Bezerra et al., 2024; Ertekin et al., 2024; Mezzetti, 2016), with a particular focus on developing innovative and resilient cropping systems (Andersson et al., 2024; Dane et al., 2016; Takeda & Soria, 2011; Udrea et al., 2024) that meet consumer demands for enhanced fruits taste and nutritional quality (Diamanti et al., 2012; Dobson et al., 2012; Fontanesi, et al., 2012; Heide & Sønsteby, 2012; Kruger et al., 2011; Mezzetti, 2016).

The production and quality of berries are influenced by various abiotic and biotic stressors (Alvarado-Raya et al, 2018; Dragišić Maksimovi et al, 2018; Laugale et al., 2018; Lepaja et al., 2018; Massetani et al., 2014; Poyraz Engin & Mert, 2018; Winardiantika et al., 2014; Yang et al., 2018; Zucchi et al., 2014), and closely monitoring of these factors can lead to significant improvements regarding yield and fruit quality (Bamouh et al, 2019; Çelik, 2018; Cho et al, 2019; Kandemir et al, 2018; Palha et al., 2018). Considering the challenges in berry production, climate change, and resource management, farmers are increasingly seeking new technological solutions (Okatan & Aşkın, 2017; Pitsioudis et al., 2008).

Also, in the context of the climate and energy targets, European Green Deal aims to achieve, with a long-term goal of net-zero greenhouse gas emissions by 2050, while supporting energy independence and economic growth (Chatzipanagi et al., 2023; Lee et al., 2023; Strapasson et al., 2017). Thus, in line with the post-2020 Common Agricultural Policy for climate adaptation and sustainability, solar photovoltaic power provides a sustainable solution (Mihălcioiu et al., 2024; Miloș et al., 2022; Mouhib et al., 2022a). Despite its benefits, photovoltaic systems require extensive land use, competing with agriculture (Ritchie & Roser, 2013; Victoria et al., 2021). To balance renewable energy expansion and food production, agrivoltaics systems offer an advanced solution (Dupraz et al., 2020; Roxani et al., 2023). By combining solar panels with farmland, agrivoltaics systems enables dual land use for both agriculture and energy production, particularly beneficial in land-scarce regions (Bonomi et al., 2021; Sahu et al., 2020). This approach can improve land efficiency, reduce water consumption, enhance crop yields, and minimize soil erosion, contributing to food security and energy sustainability (Roxani et al., 2023; Trommsdorff et al., 2022a).

This review explores the various applications of photovoltaic systems in berry production, with a particular focus on red currants. It examines the potential benefits, while also addressing the challenges associated with implementation. By analyzing recent research and case studies, this study aims to provide insights into how photovoltaic systems can transform both the agricultural and energy sectors, paving the way for a more sustainable and resilient future.

MATERIALS AND METHODS

This review was conducted using a systematic approach to identify, analyze, and synthesize relevant scientific literature on the application of photovoltaic systems in berry production, with a particular focus on red currants.

Literature search strategy – a comprehensive literature search was conducted using scientific databases, including Web of Science, Scopus, PubMed, Open Access Journals, ResearchGate, MDPI, and Google Scholar. The search utilized keywords such as - photovoltaic systems in horticulture, agrivoltaics in berries production, solar energy and fruit crops, sunburn prevention in fruit trees plantation, among others.

Selection criteria – studies were included in the review based on their relevance to photovoltaic applications, especially in fruit production, and particularly in berry crops.

Data extraction and analysis – selected studies were categorized based on their primary focus on technological advances in the field of agrivoltaics systems; definition and classification of agrivoltaics systems; applications of photovoltaic systems technology in agriculture and a global perspective of this; challenges and limitations of implementing agrivoltaics system and selection of the optimal ones; the key characteristics for selecting crops in agrivoltaics systems and the performance evaluation indicators; types of agrivoltaics systems where studies were conducted and results; the leading role of photovoltaic systems in berries production improvement; abiotic and biotic stress factors affecting red currants cultivation; the primary benefits of photovoltaic systems in red currant cultivation technology.

Key findings were summarized in a comparative framework to highlight the current knowledge and the advantages of photovoltaic systems for berry crops.

RESULTS AND DISCUSSIONS

Agrivoltaics systems, which consist of combining energy production through photovoltaic systems and agricultural production in the same area, have emerged as a promising solution to the constraints related to the reduction of cultivated areas due to the use of solar panels instead of agricultural production systems (Chalgynbayeva et al., 2023; Thompson et al., 2020; Trommsdorff et al., 2022a).

Historical agrivoltaics systems development

The concept of photovoltaic systems (PV) was first introduced by Götzberger and Zastrow in 1981, combining PV modules with potato production (Goetzberger et al., 1981).

As photovoltaic technology evolved and became more accessible (Trommsdorff et al., 2022a), the way was opened for the development of more advanced agrivoltaics systems. In Table 1 it is presented a brief history of the agrivoltaics systems development.

Classification of agrivoltaics systems

In general, an agrivoltaics system consists of a photovoltaic solar panel, a mounting/support structure, a foundation, a control and monitoring system, and the cultivated crops (Sahu et al., 2016). In recent years, several classifications of agrivoltaics systems have emerged (Sirnik et al., 2023; Trommsdorff et al., 2022a). In Table 2 are categorizes agrivoltaics systems based on different criteria, providing types and relevant references.

SWOT analysis of agrivoltaics systems – a global perspective

The main environmental and economic benefits of agrivoltaics systems include sustainability advantages such as reducing the carbon footprint, generating renewable energy, and preserving biodiversity (Al Mamun et al., 2022; Zahrawi & Aly, 2024). Additionally, they enhance economic viability by providing cost-benefit advantages for farmers, lowering energy expenses, and improving land use efficiency (Al Mamun et al., 2022; Zahrawi & Ali, 2024). Moreover, agrivoltaics systems play a crucial role in balancing renewable energy production with food security, ensuring a sustainable and profitable agricultural model (Al Mamun et al., 2022; Zainol Abidin et al., 2021). Table 3 presents the Strengths, Weaknesses, Opportunities, and Threats of agrivoltaics utilization.

Selection of the optimal agrivoltaics system

Before selecting the solar panel design and crop type, agrivoltaics system design must be aligned with the climatic factors of the intended crop to determine the optimal configuration (Ali, 2024; Hermelink et al., 2024; Stallknecht et al., 2023; Zahrawi & Aly, 2024; Wielgat et al., 2024).

AVS design requires a transdisciplinary approach (Ioannidis et al., 2020; Lee et al., 2023; Sargentis et al., 2021), and different optimization strategies must be implemented depending on the system's primary objective (Macknick et al., 2013; Trommsdorff et al., 2022b; Zainol Abidin et al., 2021). Toledo and Scognamiglio (2021) identified three fundamental categories: minimizing crop shading, maximizing electricity generation, and ensuring social acceptance.

Table 1. Technological advances in the field of Agrivoltaics Systems (AVS)

Year	Country	Details	References
1981	Germany	Concept of dual land use for solar energy and agriculture	Goetzberger & Zastrow, 1981
2004	Japan	Experimental AVS for crop protection	Maruyama et al., 2004; Tajima & Iida, 2021; Toledo & Scognamiglio, 2021
2011	France	Large-scale agrivoltaics farm implementation	Dupraz et al., 2011a
2012	Italy	First commercial AVS installed	Amaducci et al., 2018; Roxani et al., 2023
2013	South Korea	Floating AVS for rice farming	Chae et al., 2013
2016	India	Agrivoltaics for water conservation in dry climates	Dinesh & Pearce, 2016b; Trommsdorff et al., 2022 a
2017	Italy	Integration of AVS in grapes plantations	Amaducci & Yin, 2017
2017 2018	Belgium	AVS in orchard and designs (KU Leuven)	Trommsdorff et al., 2022a; Willockx et al., 2020b
2018	Italy	Elevated AVS structures on different crops	Amaducci et al., 2018
2019	China	Implementation of shading strategies for vegetable crops	Liu et al., 2019
2020	USA	AVS for berries production	Sekiyama & Nagashima, 2020
2021	Australia	Dual-use of AVS for livestock and pastureland	Barron-Gafford et al., 2021
2022	Netherlands	AI and sensor-integrated agrivoltaics systems	Weselek et al., 2022
2023	Germany	The largest AVS in the world (13 hectares)	Chalgynbayeva et al., 2023
2023	Spain	Large-scale agrivoltaics for staple crops (wheat, corn)	Sarr et al., 2023a

Table 2. Classification of Agrivoltaics Systems (AVS)

Criteria	Type	References
PV panels design	Fixed-tilt	Dupraz et al., 2011b; Hassanpour et al., 2018a; Younas et al., 2019
	Dynamic/Tracking	Amaducci et al., 2018; Sekiyama & Nagashima, 2019 a
	Vertical bifacial	Weselek et al., 2021a; Trommsdorff et al., 2021a
PV panels transparency	Opaque	Dinesh & Pearce, 2016b; Domínguez et al., 2017; Sirnik et al., 2023
	Semi-transparent	Fernández et al., 2022; Hernandez et al., 2014; Mouhib et al., 2022b; Sirnik et al., 2023; Thompson et al., 2020
Integration level	Fully Integrated AVS	Barron-Gafford et al., 2019; Majumdar & Pasqualetti, 2021
	Semi-Integrated AVS	Santra et al., 2017; Schindele et al., 2020
	Adjacent PV Installations	Chiriacò et al., 2022, Dinesh & Pearce, 2016a
Aim of installation	Energy (priority on electricity production)	Maity et al., 2023a, b; Mouhib et al., 2022a
	Crop-integrated AVS (balanced crop & energy output)	Amaducci et al., 2018; Dupraz et al., 2011a, 2011b
	Yield optimization	Amaducci et al., 2018; Majumdar & Pasqualetti, 2021
	Water conservation	Barron-Gafford et al., 2019; Trommsdorff et al. 2021a
Scale of implementation	Small-scale AVS farms (localized energy & crop use)	Barron-Gafford et al., 2019; Maity et al., 2023a, b; Sekiyama & Nagashima 2019a, 2019b, 2019c
	Large-scale AVS projects (commercial-level production)	Amaducci et al., 2018; Weselek et al., 2019; Weselek et al., 2021a, 2021b, 2021c, 2021d

Criteria	Type	References
Geographical adaptation	Arid & Semi-Arid Regions	Barron-Gafford et al., 2019; Hassanpour et al., 2018a; Trommsdorff et al., 2021a
	Temperate & Humid Regions	Amaducci et al., 2018; Chiriacò et al., 2022; Maity et al., 2023a, b; Weselek et al., 2021c, 2021d, 2021e
Integration with crops	Elevated AVS (panels above crops)	Barron-Gafford et al., 2019; Dinesh & Pearce, 2016b
	Inter-row AVS (panels between rows)	Hassanpour Adeh et al., 2018; Hernandez et al., 2014
Crop type	Pastures & Forage	Hassanpour et al., 2018a; Weselek et al., 2021a, 2021b, 2021c, 2021d
	Vegetable & Row Crops	Dinesh & Pearce, 2016a, 2016b; Hernandez et al., 2014; Marrou et al., 2013b; Sekiyama & Nagashima 2019 a, 2019b, 2019c
	Vineyards, Berries & Orchards	Dupraz et al., 2011a, 2011b; Santra et al., 2017; Trommsdorff et al., 2021b; Weselek et al., 2021a, 2021b, 2021c, 2021d, 2021e

Table 3. SWOT analysis of Agrivoltaics Systems (AVS)

Strengths (Advantages)	Weaknesses (Disadvantages)
Dual land use for agriculture and energy production – AVS maximize land efficiency by enabling both crop cultivation and solar energy production (Dupraz et al., 2011b; Maity et al., 2023a, b; Naamandadin et al., 2018). **Contribution to reducing carbon emissions and promoting renewable energy** – AVS lower reliance on fossil fuels, reducing greenhouse gas emissions (Blakers et al., 2013; Leon & Ishihara, 2018). **Long-term financial benefits** – Farmers can benefit from lower energy costs and additional income from selling excess electricity (Mouhib et al., 2022a; Solangi et al., 2011). **Improved microclimate for plant growth** – Moderate shading and temperature regulation can create a favorable environment (Barron-Gafford et al., 2019; Weselek et al., 2021a, b, c, d). **Enhance water-use efficiency and reduction of evaporation** – PV systems provide shade, reducing water requirements for crops and evaporation (Dupraz et al., 2011b; Hassanpour Adeh et al., 2018). **Protection of crops from extreme weather conditions** – PV act as a physical barrier, reducing damage from weather extremes such as hail, excessive heat, heavy rainfall (Aroca-Delgado et al., 2018; Dupraz et al., 2011b; Hassanpour et al., 2018a, b; Jamil & Pearce, 2023; Ruiz-Canales et al., 2022; Weselek et al., 2021a, b, c). **Increasing efficiency of solar panels** – The crops under PV would circulate cool air to reduce the temperature to make panels work optimally. High insolation, light winds, moderate temperature, and low humidity keep the panel's microclimate suitable for growing crops and increase panel efficiency (Ezzaeri et al., 2018; Sirnik et al., 2023).	**High initial investment costs** – The installation and maintenance of AVS require significant capital investment, which may not be feasible for all farmers (Giri & Mohanty, 2022a, b; Weselek et al., 2019). **Unpredictable effects on long-term regarding plants growth and soil health** – Additional research is necessary to assess the long-term ecological AVS impact (Maity et al., 2023a, b; Weselek et al., 2021a). **Possible reduction in sunlight exposure affecting crop yields** – In some cases, excessive shading may limit photosynthesis and can reduce potential yield of certain crops (Barron-Gafford et al., 2019; Erwin et al., 2017; Maity et al., 2023a, b; Touil et al., 2021). **Requires specialized knowledge and management** – AVS demand expertise in both energy management and agricultural practices to optimize their benefits (Dinesh & Pearce, 2016a). **Potential challenges in farm equipment operation under panel structures** – The presence of solar panels may restrict access to mechanized farm equipment (Amaducci et al., 2018; Reasoner & Ghosh, 2022). **Regulatory and legal restrictions in some regions** – Land-use policies and zoning regulations may pose barriers to agrivoltaics expansion (Dupraz et al., 2011b; Maity et al., 2023a, b; Randle-Boggis et al., 2021; Reasoner & Ghosh, 2022). **Reduced solar energy output** – Installing solar panels over crops can limit direct sunlight exposure, decreasing electricity generation per unit area and, additionally, crop shading may cause temperature variations in the panels, reducing solar cell efficiency (Macdonald et al., 2022; Randle-Boggis et al., 2021).
Opportunities	**Threats**
Increasing global demand for sustainable farming solutions – Climate change concerns and sustainable agriculture initiatives drive interest in agrivoltaics (Hernandez et al., 2014; Maity et al., 2023a). **Technological advancements in solar panel efficiency and smart farming integration** – Ongoing research is improving the efficiency of agrivoltaics systems (Amaducci et al., 2018; Maity et al., 2023a, b). **Potential for subsidies and financial support for green energy projects** – Governments and international organizations increasingly support renewable energy adoption (Maity et al., 2023a, b). **Expansion to various crop types beyond berries** – Research shows that agrivoltaics systems are adaptable to different crops, including vegetables and cereals (Barron-Gafford et al., 2019; Corwin & Johnson, 2019; Gorjian et al., 2022). **Market advantage for sustainably produced food and energy** – Consumers increasingly prefer products with a lower carbon footprint (Hernandez et al., 2014). **Contribute to local agro-economics and generates work places** – Activities such regular maintenance, vegetation management, system monitoring, panel cleaning, and repairs provide employment opportunities (Corwin & Johnson, 2019; Elavarasan et al., 2020; Prehoda et al., 2019).	**Policy changes and uncertain government incentives** – Changes in subsidies and regulatory frameworks could impact the economic viability of AVS (Dinesh & Pearce, 2016a). **Competition with alternative renewable energy and agricultural technologies** (Hernandez et al., 2014). **Land use conflicts** – AVS require significant land, this could lead to conflicts with other land uses, such as urban development, natural habitats, or other agricultural activities (Weselek et al., 2019). **Human perceptivity and resistance to land-use modification** – Communities may oppose AVS due to concerns about landscape good-looking or land rights (Weselek et al., 2019). **Risk of financial losses if system design is not optimized for local conditions** (Giri & Mohanty, 2022a, b; Mouhib et al., 2022a). **Potential impact of climate change on PV efficiency and crop adaptability** – Rising temperatures and extreme weather may affect AVS performance/production (Dupraz et al., 2011b). **Extreme weather events** – AVS may be vulnerable to extreme weather events (Kumpanalaisatit et al., 2022) **Pest and disease infestations** – Introducing PV can create new microclimates that could attract pests and diseases (Elavarasan et al., 2020).

For an agrivoltaics system to be efficient, several conditions must be met, as highlighted by Maity et al. (2023a) and Al Mamun et al. (2022): adequate solar radiation (Amaducci et al., 2018); good soil quality (Toledo et al., 2021); flat or gently sloping terrain (Williams et al., 2023); access to water; low wind risk; favorable climate conditions (Dinesh & Pearce, 2016a); sufficient space availability (Sarr et al., 2023b); and suitable land characteristics (Lorencena et al., 2019). The key factors influencing the performance of an agrivoltaics system include the height at which the panels are installed (Goetzberger et al., 1982; Hussain et al., 2017; Sarr et al., 2023a; Sekiyama & Nagashima, 2019a; Trommsdorff et al., 2022b), the panel orientation and tilt angle based on location, time of day, and period of the year (Amaducci et al., 2018; Gorjian et al., 2022; Macknick et al., 2022; Marrou et al., 2013a; Roxani et al., 2023; Sarr et al., 2023a; Scognamiglio et al., 2016; Valle et al., 2017), and the array density (Campana et al., 2021; Macknick et al., 2022; Moreda et al., 2021; Sarr et al., 2023a).

The key characteristics for selecting crops in agrivoltaics systems include the following: shade tolerance (Marrou et al., 2013b), water stress and irrigation requirements, plant height, crop lifespan (considering that photovoltaic systems typically have an operational lifespan of 30 years), pollination systems, biodiversity conservation, and resilience to climate change (Roxani et al., 2023).

The performance evaluation indicators for agrivoltaics systems are divided into two main categories (Lu et al., 2024):

Metric Indicators: these include incident radiation at ground level (Brutsaert, 1982; Roxani et al., 2023), energy efficiency (Roxani et al., 2023), crop yield (Campillo et al., 2012; Sinclair & Muchow, 1999), crop water requirements (Blackett et al., 2019; Roxani et al., 2023), and overall system performance (Roxani et al., 2023; Willockx et al., 2020a).

Economic Indicators: these include the price-performance ratio and electricity price capping (Schindele et al., 2020).

Types of agrivoltaics systems – some studies and results

In recent years, numerous researches have been carried out on the effects of different agrovoltaic systems, on **cereals** (Dupraz et al., 2011a; Jo et al., 2022; Kim et al., 2021; Lee 2022; Moreda et al., 2021; Sekiyama & Nagashima, 2019c;), ***green vegetable*** (Adomavicius, 2021; Chae et al., 2022; Erwin et al., 2017; Ezzaeri et al., 2018; Jo et al., 2022; Marrou et al., 2013b; Trommsdorff et al., 2022a, b; Weselek et al., 2021d, e), ***grapevines plants*** (Ahn et al., 2022; Malu et al.,2017; Maity et al., 2023b) and ***fruit trees*** (Claudia Hanisch, 2022; Juillion et al., 2020; Magarelli et al., 2024; Trommsdorff et al., 2022a).

In recent years, productivity assessment of some fruit growing species such as apple (Juillion et al., 2021; 2022), pear (Gim et al., 2025; Bellini, 2025; Willockx et al., 2024), peach, nectarine, cherry (Magarelli et al., 2024), kiwifruit (Basile et al., 2008; Jiang et al., 2022), have been evaluated for their suitability for growth under the photovoltaic systems.

The leading role of photovoltaic systems in berries production improvement are: optimizing growth and fruiting processes (microclimate regulation, shade effects, and photosynthesis optimization); improving resource efficiency (soil moisture retention, water conservation, and reduced irrigation needs); protection against abiotic stress (reducing sunburn, buffering temperature extremes, and wind/hail protection); enhancing fruit quality (effects on taste, texture, color, and nutritional value). In Table 4 are synthetized some results regarding the effect of photovoltaic systems on berries production. Figure 1 illustrates some berries plantations cultivated beneath solar panels.

(Source: BayWa r.e)

Figure 1. Photovoltaic systems in berry crop:
a) Raspberries; b) Red Currants

Abiotic and biotic stress factors affecting red currants cultivation

The primary factors impacting red currant production include: abiotic stressors: sunburn, drought, extreme temperatures, and soil degradation (Panfilova et al., 2021) and biotic stressors: pests and diseases influenced by environmental changes.

In Figure 2 are presented red currant cultivation climatic limiting factors.

The primary benefits of photovoltaic systems on red currant cultivation technology

Analyzing SWOT analysis presented in Table 3 and red currant requirements for vegetation factors (Figure 2), can be concluded that integrating solar panels into an agrivoltaics system offers numerous benefits for its cultivation such as growth and fruiting, improving resource efficiency, and reducing abiotic stress (Blando et al., 2018; Jung & Salmon, 2022; Jung et al., 2023).

Table 4. Effect of photovoltaic systems on berries production

Species	Results	References
Strawberries	The panels with higher transparency, demonstrated promising results regarding fruit quality for 'Sibilla' variety	Dragomir et al., 2024
	The shading from the semi-transparent PV increased the total phenolic content, as well as the free radical-scavenging activity of the harvested fruits	Petrakis et al., 2024
	Increased fruit quality due to optimized light exposure and reduced heat stress	Weselek et al., 2021d, e
	Enlarged yield and reduced water consumption under agrivoltaics shading	Amaducci et al., 2018
Blackberries	Improved productivity due to regulated microclimate and extended growing season	Magarelli et al., 2024; Maity et al., 2023a; Sarr et al., 2023 c
	Extended harvesting period, improved fruit color and sugar content	Dinesh & Pearce, 2016 a, b;
Raspberries	Enhanced photosynthesis efficiency, reduced heat stress, and increased fruit size	Marrou et al., 2013; Sekiyama & Nagashima, 2019b
	Decreased sunburn damage and better preservation of fruit firmness and color	Dupraz et al., 2011; Jamil & Pearce, 2023
Blueberries	Enhanced fruit quality, improved water-use efficiency, and protect against extreme weather conditions	Adeh et al., 2019; Barron-Gafford et al., 2019; Hassanpour et al., 2018b; Hermelink et al., 2024; Majidi et al., 2023
Red currants	Higher antioxidant content, improved resource efficiency, and better fruit appearance	Weselek et al., 2021d, e
	Enhanced photosynthetic efficiency and improved fruit size and taste	Aroca-Delgado et al., 2018; Ruiz-Canales et al., 2022
Black currants	Higher sugar content and improved fruit coloration under agrivoltaics systems	Maity et al., 2023a, b; Weselek et al., 2021a, b, c
Gooseberries	Protection from sunburn and increased shelf life	Obergfell et al., 2021
	Better protection from frost and extreme weather, leading to stable yields	Lorencena et al., 2019; Toledo et al., 2021
Cranberries	Lower water consumption and stabilized temperature in cultivation areas	Touil et al., 2022
	Increased resistance to drought stress and improved water conservation	Dinesh et al., 2016b; Williams et al., 2023
Lingonberries	Higher vitamin C content and improved frost resistance	Trommsdorff et al., 2021b
	Enhanced fruit quality and antioxidant content due to optimized shading	Sahu et al., 2016; Sarr et al., 2023c
Elderberries	Improved fruit set and resistance to pests due to favorable microclimate	Hassanpour et al., 2018a

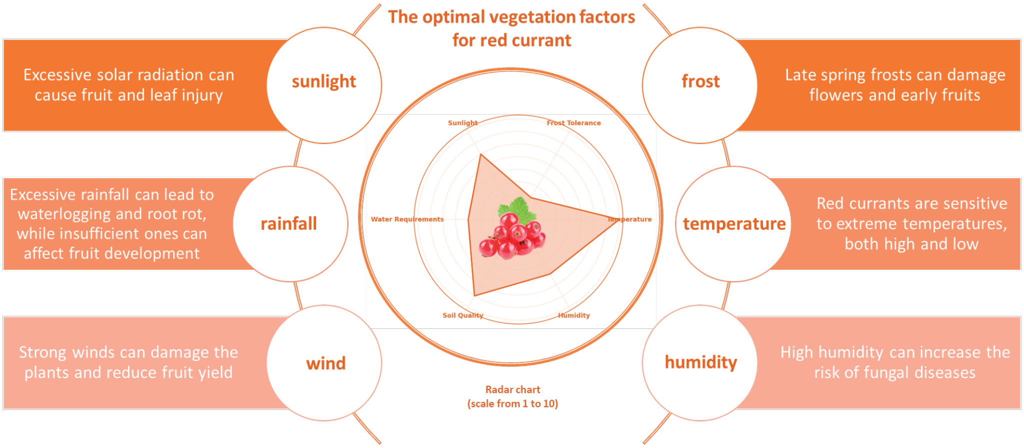

Figure 2. The main climatic limiting factors for red currant cultivation (Source: original)

The primary benefits of PV systems in fruit berries growing technology include protection against hail, frost, and drought, as well as providing partial shading, which is essential for species sensitive to direct sunlight, such as currants.

CONCLUSIONS

The integration of photovoltaic systems in berry production offers a promising path toward sustainable and resilient agriculture. By optimizing resource use, reducing climate-related stress, and improving fruit quality, agrivoltaics solutions can play a vital role in the future of horticulture. Advancements in technology, including smart PV systems, AI-driven monitoring, and precision agriculture, will be essential for enhancing efficiency, scalability, and long-term benefits. These innovations will further support sustainability, making berry production more adaptable to environmental challenges while ensuring economic viability for farmers.

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