

Influence of Agriphotovoltaic Growing Conditions on the Quality Characteristics of Cabbage (*Brassica oleracea* var. capitata)

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Abstract

This study systematically analyzes the effects of different agriphotovoltaic cultivation conditions on the quality attributes of cabbage. The experiment was implemented using a restricted randomized block design (RBD) with seven treatments and three replications. The treatment of growing cabbage in treatment (T₇) i.e where cabbage grown in open field condition showed significantly higher performance compared to other treatments under investigation in quality parameters of cabbage such as TSS (Total Soluble Solid) (6.03 %), ascorbic acid content (43.77 mg/100g), shelf life at room temperature (8.03 days), and at refrigerated condition (16.13 days). The highest values for moisture content (92.59 %) was recorded in treatment (T₅) where cabbage grown below 3.75 m bifacial photovoltaic panel height with 5.65 m pitch distance.

Keywords: Agriphotovoltaic, Cabbage, Photovoltaic panel, Quality parameters

Introduction

India ranks second after China in cabbage production, accounting for 16.55% of the

global cultivation area and 12.79% of total output. In 2024, Maharashtra produced about 247.35 million tonnes from 130,000 hectares.

Cabbage is widely grown for domestic use and export, especially in cooler states like Himachal Pradesh, West Bengal, and Uttar Pradesh. It is an essential part of Indian cuisine and agriculture, though affected by pests and market fluctuations. Cabbage is a nutritious, low-calorie vegetable rich in vitamins A, B1, B2, and C. (Hanif *et al.*, 2006) It is widely consumed across all income groups in various forms—raw, cooked, or preserved—and is valued for its health benefits and medicinal properties.

To ensure long-term environmental sustainability, transitioning to renewable energy is essential for lowering carbon emissions and addressing climate change. Implementing clean, renewable energy sources is key to minimizing the serious impacts of climate change, including more frequent droughts, floods, intense rainfall, and heatwaves. Solar energy is one of the most accessible and abundant sources among all clean and renewable energy options. (Malu *et al.*, 2017; Moreira *et al.*, 2020).

Agriphotovoltaics is the simultaneous use of the area of land for both Solar Energy and agriculture. The PM-KUSUM scheme promotes the “Solarization” of agriculture. This scheme promotes the setting up of small-scale decentralized grid-connected solar power plants on farmer’s land. The APV system is still an emerging concept, with few studies exploring its impact on crop productivity. Consequently, significant research is needed to optimize agricultural output, develop effective management strategies, and fully harness the potential benefits of the GM-APV system. In India, AgriPV is still under development stage through a few pilots. The use of AgriPV offers many key benefits to a densely populated country like India. The benefits include rural electrification, water conservation, agriculture yield improvement, and sustainable income generation. Recent research on agrivoltaic (APV) systems has largely emphasized crop yield. However, modern consumers are also placing greater importance on the flavor and overall quality of crops, aiming for higher

nutritional content. Hence, investigating crop quality within agriphotovoltaic systems is essential. Accordingly, the present study was conducted to examine the quality attributes of cabbage under different agriphotovoltaic growing conditions.

Materials and methods

The study was conducted during the Rabi season of 2024–25 at the Agriphotovoltaic Research Project, Manwat, under VNMKV, Parbhani. The field was divided into three agrivoltaic (APV) sections and one open control. The APV setup included zones under panels, between panels, and adjacent open areas. Three types of PV panels (20% efficiency, 11° tilt) were used: bifacial (3.75 m clearance, 5.65 m pitch), monofacial (1.75 m clearance, 7.5 m pitch), and bifacial (1.75 m clearance, 10 m pitch). Healthy 3-week-old cabbage seedlings were transplanted at a spacing of 60 cm × 60 cm on raised beds situated both under photovoltaic panels and in open field conditions. Treatment details consist of planting zucchini in the treatment T₁ – below 1.75 m monofacial photovoltaic panel height with 7.5 m pitch distance, treatment T₂ – in between 1.75 m monofacial photovoltaic panel height with 7.5 m pitch distance, treatment T₃ – below 1.75 m bifacial photovoltaic panel height with 10 m pitch distance, treatment T₄ – in between 1.75 m bifacial photovoltaic panel height with 10 m pitch distance, treatment T₅ – below 3.75 m bifacial photovoltaic panel height with 5.65 m pitch distance, treatment T₆ – in between 3.75 m bifacial photovoltaic panel height with 5.65 m pitch distance and treatment T₇ – control i.e. open field condition. All quality parameters were recorded after of harvest. The data collected was subjected to statistical analysis of variance as suggested by Panse and Sukhatme (1985).

Results and discussion

Quality parameters of cabbage

The impact of various agriphotovoltaic growing conditions on cabbage quality parameters showed significant variation across treatments,

as presented in Table 1. Maximum moisture content was observed in treatment (T₅) (92.59 %) where cabbage grown below 3.75 m bifacial photovoltaic panel height with 5.65 m pitch distance and it was statistically at par with the treatment growing cabbage in between 3.75 m bifacial PV panel height with 5.65 m pitch distance *i.e* (T₆) (90.84 %). While, minimum moisture content was recorded in treatment (T₇) (87.12 %) *i.e* growing cabbage in open field condition. This increase might be due to the moderated microclimate under the solar panels, which reduced solar radiation and evapotranspiration, thereby enhancing moisture retention in the plant tissues. Min *et al.*, (2022) investigated the effects of environmental changes induced by agrivoltaic systems on the growth and quality characteristics of kimchi cabbage.

Maximum TSS content in cabbage was recorded in treatment (T₇) (6.03 %) *i.e* growing cabbage in open condition and it was statistically at par with the treatment (T₄) (5.67 %) and (T₃) (5.40 %). While, minimum TSS content in cabbage was recorded in treatment (T₅) (4.33 %). The reduced TSS content in cabbage under agriphotovoltaic conditions might be due to limited light availability caused by shading from solar panels. Light is a key factor which directly affects the synthesis and accumulation of sugars in plant tissues. Reduced photosynthetic activity under shaded conditions can lead to lower sugar content, thereby decreasing the total soluble solids (TSS) in the cabbage. The results are in line with those reported by El-Gizawy *et al.*, (1993) in tomato and Ferrara *et al.*, (2023) in grapes.

The results revealed that, significantly maximum ascorbic acid content in cabbage was recorded in treatment (T₇) (43.77 mg/100g) *i.e* growing cabbage in open field condition and it was statistically at par with the treatment (T₄) (42.97 mg/100g). While, significantly minimum ascorbic acid content in cabbage was observed in treatment (T₅) (39.53 mg/100g). Vitamin C content was found to be lower in crops grown under agriphotovoltaic (APV) systems compared to open-field conditions.

This reduction is primarily attributed to decreased light intensity and altered light quality under the solar panels, which can limit ascorbic acid biosynthesis. As Vitamin- C production is light-dependent, particularly influenced by UV and blue light, the shading effect in APV systems likely reduced its accumulation. Hassanien *et al.*, (2022) in chilli report supports the present findings.

Significantly maximum shelf life at room temperature was observed in treatment (T₇) (8.03 days) *i.e* growing cabbage in open field condition and it was followed by the treatment (T₄) (7.67 days). While, significantly minimum shelf life at room temperature was recorded in treatment (T₅) (6.30 days). Significantly maximum shelf life at refrigerated condition was observed in treatment (T₇) (16.13 days) *i.e* growing cabbage in open field condition and it was statistically at par with the treatment (T₄) (15.87 days) and treatment (T₃) (15.60 days). While, significantly minimum shelf life at refrigerated condition was observed in treatment (T₅) (13.20 days). Cabbage from open field conditions, with relatively lower moisture content, showed better shelf life and maintained post-harvest quality for a longer period. This indicates a clear trade-off between improved water retention under APV and reduced storage potential, emphasizing the need for appropriate post-harvest handling to enhance shelf life under such systems. These findings are in accordance with the findings of Marrou *et al.*, (2013) in lettuce and Hassanien *et al.*, (2022) in chilli pepper.

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Conflict of interest

The authors confirm that this research was conducted without any commercial or financial

associations that might be seen as a potential conflict of interest.

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Table 1. Influence of different agriphotovoltaic growing conditions on quality parameters of cabbage

Treatment number	Treatment details	Moisture content (%)	TSS (%)	Ascorbic acid (mg/100g)	Shelf life at room temp.	Shelf life at refri. condition
T ₁	Below 1.75 m monofacial PV panel height with 7.5 m pitch distance	89.55 (71.14)*	4.77	39.83	6.60	14.97
T ₂	In between 1.75 m monofacial PV panel height with 7.5 m pitch distance	89.02 (70.65)	4.90	40.67	6.73	15.13
T ₃	Below 1.75 m bifacial PV panel height with 10 m pitch distance	88.43 (70.11)	5.40	41.23	7.10	15.60
T ₄	In between 1.75 m bifacial PV panel height with 10 m pitch distance	87.46 (69.26)	5.67	42.97	7.67	15.87
T ₅	Below 3.75 m bifacial PV panel height with 5.65 m pitch distance	92.59 (74.20)	4.33	39.53	6.30	13.20
T ₆	In between 3.75 m bifacial PV panel height with 5.65 m pitch distance	90.84 (72.38)	4.53	39.57	6.43	14.17
T ₇	Open field condition	87.12 (68.97)	6.03	43.77	8.03	16.13
S.E m±		0.89	0.22	1.36	0.1	0.23
C.D.@5%		2.76	0.68	4.19	0.32	0.74