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Physical parameters and nutraceutical properties of zucchini (*Cucurbita pepo* L.) as affected by different agriphotovoltaic growing conditions

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Abstract

Present study comprehensively examines the influence of different agriphotovoltaic growing conditions on physical parameters and nutraceutical properties of zucchini. The experiment was conducted using restricted randomized block design (RBD) with seven treatments and three replications. The treatment of planting zucchini in between 1.75 m bifacial photovoltaic panel height with 10 m pitch distance showed significantly higher performance compared to other treatments under investigation in physical parameters of fruit such as fruit length (21.79 cm), fruit diameter (5.14 cm), fruit circumference (16.15 cm) and fruit weight (273.78 g). The highest values for nutraceutical properties *i.e.* total soluble solids (4.44%), ascorbic acid content (14.23 mg/100g), fiber content (0.88%) were also recorded for same treatment. While, highest moisture content (95.03%) was observed in treatment where zucchini grown in between 3.75 m bifacial photovoltaic panel height with 5.65 m pitch distance.

Keywords: Agriphotovoltaic, Nutraceutical properties, Physical parameters, Photovoltaic panel, Zucchini

1. Introduction

Cucurbita pepo L. or zucchini, is a member of the Cucurbitaceae family and is originated in Mesoamerica, which is the region of North America. It is exotic vegetable that has gained significant popularity in India in recent years. Zucchini is nutritionally important as it is low in calories yet rich in dietary fiber, vitamins, minerals and antioxidants which support digestion, heart health and overall well-being.
The demand for food and energy is increasing day by day and their security has become the key challenge in mainly developing countries like India. Agri-voltaic system has been introduced as an integrated strategy, combining photovoltaic with agriculture simultaneously on the same land to capture solar energy for both energy generation and food production. Depending on their needs for light, temperature and root structure, crops are grown in the area between and under the photovoltaic panels.

Agriphotovoltaic technology is being applied worldwide, there is very less accompanying scientific research to examine its impacts on growth, yield and quality of crop. However, various reports in China (Hassanien and Li, 2017), Spain (Aroca Delgado *et al.*, 2019), Italy (Buttaro *et al*., 2016), USA (Barron-Gafford *et al*., 2019), France (Marrou *et al.*, 2013), Germany (Trommsdorff *et al.*, 2021) and India (Malu *et al.*, 2017) have attempted research by integrating APV modules on certain areas of the crop production along with energy generation. Recent research on APV has mainly focused on the crop yield under agrivoltaics system. Yet modern consumers are also interested in the taste and quality of crops so as to obtain more nutritional quality. Therefore, conducting research to determine crop quality under agriphotovoltaic system is essential. Hence, present investigation carried out with the objective to study the physical parameters and nutraceutical properties of zucchini under different agriphotovoltaic growing conditions.

2. Materials and methods

Present study was carried out at Agriphotovoltaic Research Project, Manwat, run under Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani during the *rabi* season of the year 2024-25. The field is categorised into four sections- three agrivoltaic (APV) and one open *i.e.* control section (non APV). The agriphotovoltaic site includes areas below solar panels, in between panels and open area outside the photovoltaic system. The photovoltaic panel specification includes three types of panels, all with 20% efficiency and 11°tilt. The ground clearance of panels varies as 3.75 m (bifacial), 1.75 m (monofacial) and 1.75 m (bifacial) with pitch distance of 5.65 m, 7.5 m and 10 m, respectively.

The experiment was laid out in restricted randomized block design (RBD) consisting of seven treatments replicated thrice. The nursery raising of “Himani” zucchini variety seeds was done in pro-trays. Zucchini seedlings were transplanted after 15 days of sowing on main experimental plot at spacing 60 × 60 cm under photovoltaic panel, in between the photovoltaic panel rows and in open field condition. Treatment details consist of planting zucchini in the treatment T_1 – below 1.75 m monofacial photovoltaic panel height with 7.5 m pitch distance, treatment T_2 – in between 1.75 m monofacial photovoltaic panel height with 7.5 m pitch distance, treatment T_3 - below 1.75 m bifacial photovoltaic panel height with 10 m pitch distance, treatment T_4 – in between 1.75 m bifacial photovoltaic panel height with 10 m pitch distance, treatment T_5 – below 3.75 m bifacial photovoltaic panel height with 5.65 m pitch distance, treatment T_6 – in between 3.75 m bifacial photovoltaic panel height with

5.65 m pitch distance and treatment T_7 – control *i.e.* open field condition (non APV). All physical parameters of fruit and nutraceutical properties were recorded after harvest. The moisture%, ascorbic acid content and fiber% were determined by procedure suggested by (Ranganna, 1986), TSS was measured by hand refractometer. The data collected was subjected to statistical analysis of variance as suggested by Panse and Sukhatme (1985).

3. Results and discussion

3.1 Physical parameters of fruit:

Effect of different agriphotovoltaic growing conditions on physical parameters of fruit showed significant difference among treatments which is given in Table 1. The longest fruit length (21.79 cm) was recorded in treatment T_4 where zucchini planted in between 1.75 m bifacial photovoltaic panel height with 10 m pitch distance over rest of the treatments under study. It was statistically at par with treatment T_2 (20.12 cm) and treatment T_1 (19.58 cm). The treatment T_7 (16.75 cm) where zucchini grown in open field condition (non APV) recorded the shortest fruit length. The maximum fruit diameter (5.14 cm) was noticed in treatment T_4 which was statistically at par with treatment T_2 (5.02 cm) and treatment T_1 (4.88 cm). While minimum fruit diameter (3.65 cm) was recorded in treatment T_7 where zucchini planted in open field condition *i.e.* (non APV). The maximum fruit circumference of zucchini (16.15 cm) was observed in treatment T_4, however it was statistically at par with treatment T_2 (15.76 cm) and treatment T_1 (15.31 cm). Whereas, minimum value of fruit circumference (11.46 cm) was recorded in treatment T_7. The maximum fruit weight (273.78 g) was recorded in treatment T_4 which outperformed the other treatments under investigation. It was followed by treatment T_2 (265.27 g). While, minimum fruit weight (207.49 g) was observed in treatment T_7. These variations in physical parameters could be attributed to better light diffusion and moderated microclimatic conditions, especially in the case of bifacial panels, which allow reflected light from both sides. This contributed to healthier foliage and better physiological functioning, reflected in overall fruit development. These results are in close proximity with the findings of Tang *et al.* (2020) in strawberry and Mani *et al.* (2025) in turmeric.

3.2 Nutraceutical Properties:

Perusal of data presented in Table 2 clearly revealed that different agriphotovoltaic growing conditions influenced the nutraceutical properties of zucchini. The maximum value of total soluble solids (4.44%) was noticed in treatment T_4 where zucchini grown in between 1.75 m bifacial photovoltaic panel height with 10 m pitch distance over rest of the treatments under experimentation. It was statistically at par with treatment T_2 (4.21%), treatment T_1 (4.04%) and treatment T_7 (3.93%). While, minimum value recorded for total soluble solid content (3.31%) was in treatment T_6 where zucchini planted in between 3.75 m bifacial panel with pitch distance 5.65 m. Among various treatments, the highest ascorbic acid (14.23 mg/100g) was observed in treatment T_4. It was statistically at par with treatment T_2 (14.05 mg/100g), treatment T_1 (13.64 mg/100g) and treatment T_7 (13.22 mg/100g) *i.e.* open field condition (non APV). While, minimum value recorded for ascorbic acid content (12.48 mg/100g) was in treatment T_6. The maximum value of fiber content (0.88%) was recorded in treatment T_4. It was followed by treatment T_2 (0.86%), treatment T_1 (0.86%) and treatment T_7 (0.85%). The minimum value of fiber content

(0.83%) was observed in treatment T_6. These variations in nutraceutical properties might be due to moderate shading under 1.75 m panel height, especially between panels, which reduced transpiration and helped to maintain optimal fruit metabolism and sugar accumulation. It reduces photoinhibition and maintains favourable light quality (diffuse radiation) which may enhance antioxidant biosynthesis, including ascorbic acid. It also favours cell wall development and fiber biosynthesis. The results are in line with those reported by Tang *et al.* (2020) in strawberry and Ferrara *et al.* (2023) in grapes.

Table 1. Influence of different agriphotovoltaic growing conditions on physical parameters of fruit of zucchini

Tr. No.	Treatment details	Fruit length (cm)	Fruit diameter (cm)	Fruit circumference (cm)	Fruit weight (g)
T_1	Below 1.75 m monofacial photovoltaic panel height with 7.5 m pitch distance	19.58	4.88	15.31	256.21
T_2	In between 1.75 m monofacial photovoltaic panel height with 7.5 m pitch distance	20.12	5.02	15.76	265.27
T_3	Below 1.75 m bifacial photovoltaic panel height with 10 m pitch distance	18.67	4.41	13.84	244.53
T_4	In between 1.75 m bifacial photovoltaic panel height with 10 m pitch distance	21.79	5.14	16.15	273.78
T_5	Below 3.75 m bifacial photovoltaic panel height with 5.65 m pitch distance	18.14	4.15	13.02	231.55
T_6	In between 3.75 m bifacial photovoltaic panel height with 5.65 m pitch distance	17.90	3.92	12.32	222.25
T_7	Open field condition	16.75	3.65	11.46	207.49
S.E m±		0.96	0.18	0.57	2.63
C.D. @ 5 %		2.95	0.56	1.74	8.11

Table 2. Influence of different agriphotovoltaic growing conditions on nutraceutical properties of zucchini

Tr. No.	Treatment details	Moisture %	TSS (%)	Ascorbic acid (mg/100g)	Fiber %
T_1	Below 1.75 m monofacial photovoltaic panel height with 7.5 m pitch distance	93.90 (75.62)*	4.04	13.64	0.86 (5.32)*
T_2	In between 1.75 m monofacial photovoltaic panel height with 7.5 m pitch distance	93.54 (75.19)	4.21	14.05	0.86 (5.32)
T_3	Below 1.75 m bifacial photovoltaic panel height with 10 m pitch distance	94.14 (75.91)	3.75	13.02	0.84 (5.25)
T_4	In between 1.75 m bifacial photovoltaic panel height with 10 m pitch distance	93.37 (75)	4.44	14.23	0.88

					(5.38)
T_5	Below 3.75 m bifacial photovoltaic panel height with 5.65 m pitch distance	94.45 (76.29)	3.66	12.77	0.84 (5.25)
T_6	In between 3.75 m bifacial photovoltaic panel height with 5.65 m pitch distance	95.03 (77.03)	3.31	12.48	0.83 (5.22)
T_7	Open field condition	93.05 (74.63)	3.93	13.22	0.85 (5.28).
S.E m±		0.45	0.21	0.35	0.013
C.D. @ 5 %		1.40	0.65	1.08	0.039

*Figures in parentheses indicate arcsine transferred values

The treatment T_6 (95.03%) where zucchini grown in between 3.75 m bifacial photovoltaic panel height with 5.65 m pitch distance recorded the highest moisture content over rest of the treatments under study. It was statistically at par with treatment T_5 (94.45%) and T_3 (94.14%). However, the lowest moisture content was observed in treatment T_7 (93.05%) where zucchini planted in open field condition (non APV). These results are might be due to optimal light diffusion, lower canopy temperature and better air movement under 3.75 m bifacial panel height with 5.65 m pitch distance, all of which reduce transpiration losses and resulted into high moisture content. These results are in agreement with the findings of Min *et al.* (2022) in cabbage and Scarano *et al.* (2024) in tomato.

4. Conclusion

Summarizing the present investigation in the light of obtained results, it may be concluded that among seven treatments under study, the planting zucchini in between 1.75 m bifacial photovoltaic panel height with 10 m pitch distance showed superior performance in physical parameters of fruits such as fruit length, fruit diameter, fruit circumference, fruit weight and nutraceutical properties like total soluble solids, ascorbic acid content, fiber %.

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6. Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be constructed as a potential conflict of interest.

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