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Mustard (*Brassica rapa*) and Eggplant (*Solanum melongena*) Cultivation in Agrivoltaic System in Coastal Area, Case Study of Baron Technopark, Yogyakarta

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ABSTRACT

Agrivoltaic is a system developed from plant cultivation and photovoltaic installations. Opportunities for creating this system in Indonesia are still quite large, including in the Gunungkidul Yogyakarta area. This study aimed to determine the growth response and yield of mustard greens and eggplant in the Agrivoltaic system in Baron, Gunungkidul, Yogyakarta, as a preliminary study of the use of photovoltaic for plant cultivation activities. The research was conducted in a photovoltaic installed in the Baron Techno Park area, BRIN, Gunungkidul Regency, Yogyakarta. An unpaired T-test design was used in this research, which compared the growth and yield of mustard greens and eggplant under and outside the solar panels. The development of mustard and eggplant plants showed quite a high variation between rows below and outside the panel. Therefore, the rows were also used as a treatment in this research. The results showed that mustard greens and eggplants can be grown in agrivoltaic systems. The location of the plants (below and outside the panel) did not affect the growth and yield of mustard plants, while eggplant did. The position of the row inside and outside the panel also affects the growth and yield of mustard greens and eggplant. Mustard and eggplant plants planted outside the panels will be harvested 15 days faster than those under the panels.

Keywords: *Agrivoltaic, Baron, Gunungkidul, Green Mustard, Eggplant*

1. INTRODUCTION

Food and energy are crucial aspects that require sustainable support to ensure optimal utilization for the betterment of society. The cultivation system primarily focuses on producing food and horticultural crops. In traditional and modern agricultural practices, energy plays a significant role in various forms (Garcia & Callejo, 2022). Energy is essential for land processing, maintenance, and harvesting. Additionally, agricultural cultivation indirectly generates energy through biomass production. Biomass is derived from plants that convert sunlight into plant material through photosynthesis (McKendry, 2002). Consequently, biomass is a vital energy source for humans and falls under renewable energy sources. Renewable energy will play a crucial role in meeting the escalating energy demands in a sustainable and environmentally friendly manner. Alongside biomass, solar power derived from sunlight is the most abundant and readily available source among all renewable energy sources (Chamara & Beneragama, 2020). Therefore, energy acts as the connecting link between agricultural crop cultivation and solar power.

Agrivoltaics is a method that integrates plant cultivation with solar power in the exact location (Santra et al., 2018). According to Kostik et al. (2020), an agrivoltaic system can efficiently use land by producing food, fuel, or energy. Solar panels must be installed over a considerable area to harness energy from a solar power system. The placement of these panels may impact the microclimatic conditions of the region, leading to an increase in temperature beneath the solar panels. However, having plants underneath or in between the solar panels can help mitigate this rise in temperature. Agrivoltaic systems offer advantages in terms of temperature regulation for both the solar panels and the plants (Garcia & Callejo, 2022). Plants engage in evapotranspiration, which indirectly contributes to lowering the temperature beneath the solar panels. Conversely, installing solar panels can decrease evapotranspiration in plants, thereby reducing water loss in both plants and soil.

Agrivoltaics has not gained significant traction in Indonesia, unlike in several other Asian countries such as Japan, India, and Malaysia, where Agrivoltaic projects have been previously implemented (Maity et al., 2023). Similarly, research and publications on agrivoltaics or using solar panels/energy for plant cultivation in Indonesia are scarce. However, Hidayanti et al. (2019) successfully employed solar panels in a hydroponic system for plant cultivation, while Budiyanto et al. (2022) utilized solar power for hydroorganic rice farming. Consequently, further research is imperative to explore the potential of agrivoltaics, particularly in the context of plant cultivation.

The selection of plants in an agrivoltaic system involves various considerations. While almost all plants can be utilized, including horticultural crops, food crops, and fruits, certain factors must be considered. For instance, vines can be planted vertically in an agrivoltaic system using poles on solar panels (Malu et al., 2017). The height of the plants is an important consideration when choosing plant types for an agrivoltaic system to ensure they do not obstruct the solar panels, particularly in the case of vegetable plants (Santra et al., 2018). Gafford et al. (2019) conducted a study using three plant varieties from the Solanaceae family, namely tomatoes, jalapeño peppers, and chiltepin peppers, in an agrivoltaic system. Chamara & Beneragama (2020) mentioned that food crops and vegetables can be cultivated in agrivoltaic systems, especially those that can adapt to limited sunlight. Even rice plants, which typically require full sunlight, can be grown using an agrivoltaic system by carefully considering the shape and arrangement of the solar panels (Gonocruz et al., 2021).

In this study, the selection of mustard greens and eggplant was based on several considerations. Both plants have relatively large or broad leaves that can maximize the process of photosynthesis, thus influencing the reduction of temperature beneath the solar panel. Mustard greens have a relatively short growing period, enabling quick yield, while eggplants have a plant height that is compatible with the size of the solar panels installed in the research location. Eggplants have a longer production lifespan and can be harvested multiple times. Moreover, both plants exhibit superior adaptability to reasonably extreme environmental conditions.

study observed variations in environmental factors including temperature, humidity, wind speed, wind direction, and sunlight duration. Damayanti and Ranum (2008) highlighted the distinct ecological features of each beach in Gunungkidul Regency, such as wave patterns, ocean currents, temperature, salinity, and sea pH. Additionally, the region is characterized by karst topography from Gunungsewu, which poses challenges for plant cultivation. Wahyuhana and Sukmawati (2019) noted that the southern coast of Gunungkidul Regency exhibits unique topographic features, mainly undulating hills on karst formations. This geographical setting can lead to uneven water distribution, potentially resulting in drought and decreased land productivity. Winarno et al. (2003) mentioned that staple food crops like cassava, rice, corn, and peanuts are commonly grown in the area through intercropping practices. However, the cultivation of horticultural plants, such as vegetables, is limited due to suboptimal land and environmental conditions for plant development.

Therefore, this research was conducted to understand the growth response and yield of mustard greens and eggplants in the Agrivoltaic system in Baron, Gunungkidul, Yogyakarta, as an initial study of solar panel utilization for farming activities.

2. MATERIAL AND METHODS

The study was conducted in the Baron Techno Park area, which is situated in Ngresik, Kanigoro, Saptosari District, Gunungkidul Regency, Yogyakarta (Figure 1). The research site experiences varying environmental conditions and is prone to extreme conditions due to its location in Baron, the southern coast of Java (Figure 2). The initial investigation was conducted in early 2022 (Ahmad et al., 2022), and the research activities were carried out from May to October 2022.

Figure 1. Research Location

Figure 2. Research site

The research utilized green mustard seeds (caisim) of the Shinta F1 variety, eggplant seeds of the kopek type (long round fruit with a colored blunt tip) of the Yuvita F1 variety, manure, liquid organic fertilizer, NPK fertilizer, insecticide (decis), herbicide, 20 cm diameter polybag (for mustard greens), and 30 cm diameter polybag (for eggplant). The equipment employed included pot trays for seeding activities, hoes, and spatulas for planting, sprinklers and water hoses for maintenance/watering, cutting scissors and scales for harvesting, rulers, tape measures, calipers, and leaf area meters for measuring leaf area.

The experimental method used in the research involved an unpaired T-test design to compare the growth and yield of mustard greens and eggplant planted in polybags under and outside the solar panels (Figure 3).

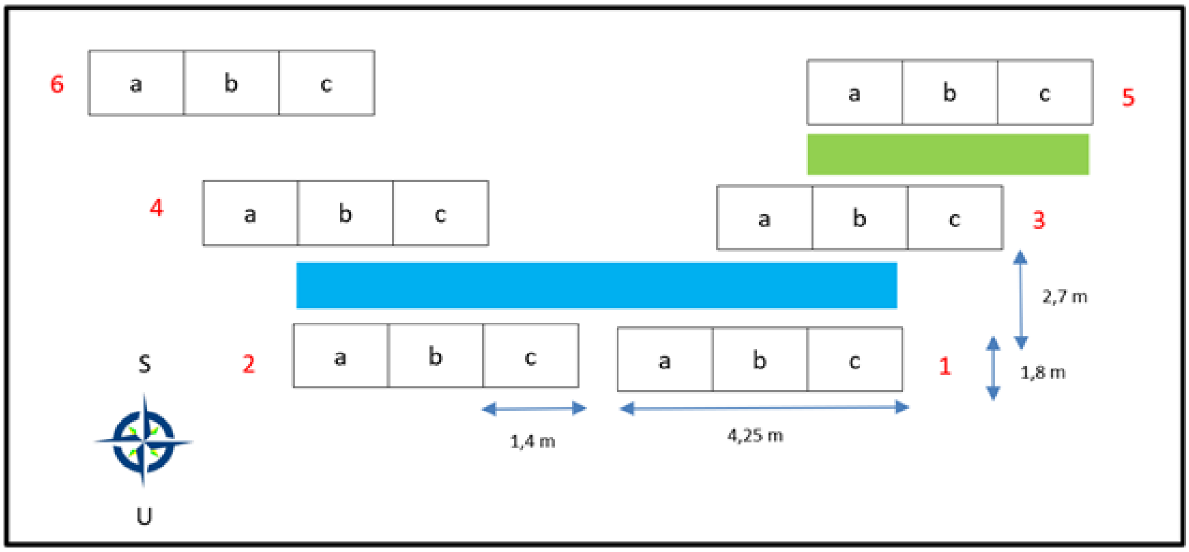

Figure 3. Plan of the research site

The mustard plants are positioned in panel 5. situated below the panel, as well as in the green box located outside the panel. On the other hand, the eggplant plants are placed in panels 1 and 2 below the panel and in the blue box outside the panel. The growth of mustard and eggplant plants exhibits significant variations when comparing the rows below the panel with those outside the panel. Consequently, in this research, the rows were utilized as treatments in a Completely Randomized Design, with the location or position of the plant rows serving as the sole treatment.

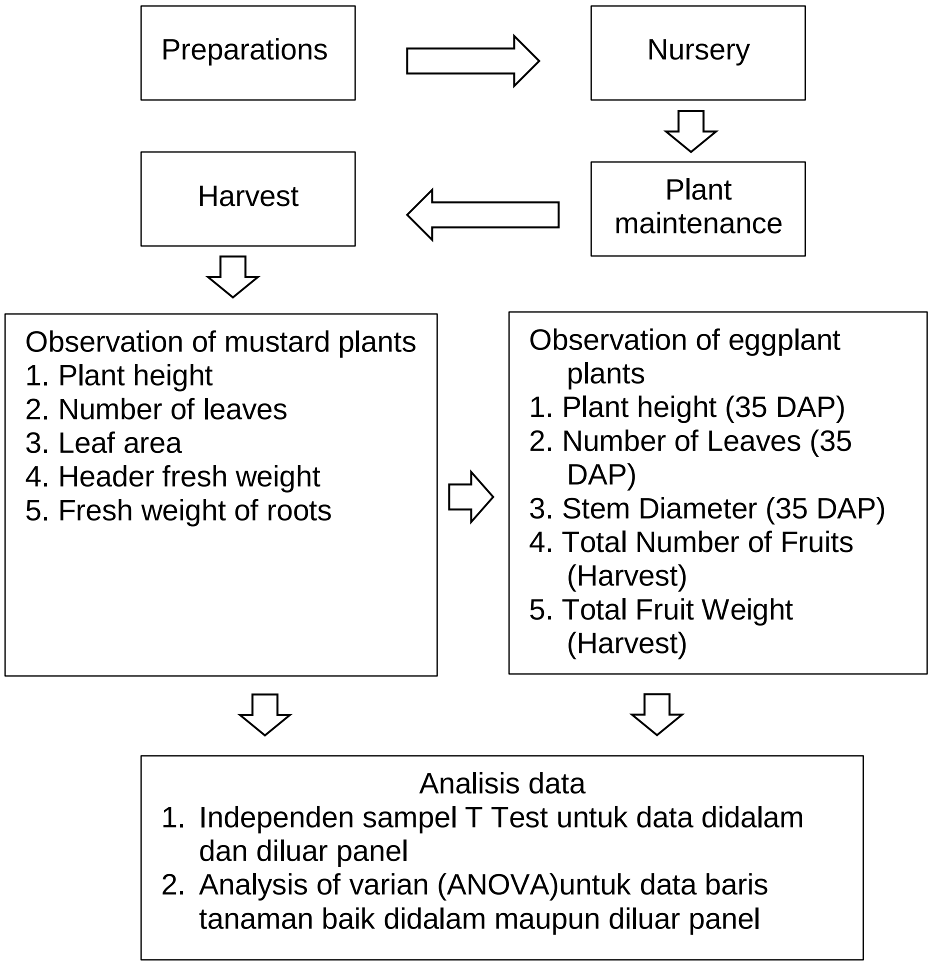

Figure 4. Research Flow Diagram

The study followed the research flow diagram depicted in Figure 4. It should be noted that this research serves as a preliminary investigation, and therefore, the growth and yield parameters of the plants observed are not yet fully complete. These parameters include plant height, number of leaves, mustard plant leaf area, fresh weight of the mustard plant canopy, weight of fresh roots of mustard plants, stem diameter of eggplant plants, total number of eggplant fruit per plant, and total weight of eggplant fruit per plant. In the case of mustard plants, plant height measurements were conducted at the time of harvesting. On the other hand, plant height was measured once for eggplant plants, precisely 35 days after planting (DAP) or at the maximum vegetative stage, indicated by the presence of flowering in several plants. The mustard plant leaves were counted during harvesting, while leaf counts were conducted at 35 DAP for eggplant plants. Leaf area measurements were carried out using a leaf area meter on selected harvested mustard leaf samples. Similarly, the stem diameter measurement for eggplant plants was done once, at 35 DAP, using a caliper. The research data obtained was analyzed using the Independent Sample T-Test for data within and outside the panel. Furthermore, Analysis of Variance (ANOVA) was employed to analyze the plant row data within and outside the panel, with a significance level of 5%. In cases where significant differences were observed from the ANOVA results, further testing was conducted using Duncan's Multiple Range Test (DMRT). The statistical analysis was performed using the IBM SPSS Statistics 22 application.

The study encompassed a comprehensive four-stage process: preparation, seeding and planting, maintenance, and harvesting. The initial stage involved meticulous preparation. The designated area was meticulously cleared of weeds, both beneath and outside the panels, utilizing herbicide to ensure a conducive research environment. For mustard greens, a plant spacing of 25 cm within rows and 40 cm between rows was employed, resulting in five plants per panel. Conversely, a plant spacing of 50 cm within rows and 80 cm between rows was adopted for eggplant plants, yielding three rows per panel. The chosen planting distances were tailored to accommodate the solar panel structures utilized in the study. The planting medium consisted of a mixture of soil and manure in a 1:1 ratio.

The second phase involves the process of seeding and planting. Initially, mustard and eggplant seeds are sown before being transplanted into polybags. Following this, the third phase focuses on maintenance. Regular watering is conducted daily, either in the morning or evening. The growth stage of the plants determines the amount of water provided. Regarding fertilizers, the study employed NPK fertilizer and liquid organic fertilizer. For mustard plants, 3 g/plant of NPK fertilizer is administered twice, specifically at the 2-week and 4-week marks after planting. This dosage aligns with the findings of Letahiit et al. (2022). On the other hand, eggplant plants receive a dosage of 20 g/plant of NPK fertilizer, also given twice, at the 2-week and 8-week intervals after planting. This dosage is based on the research conducted by Raksun et al. (2019), who concluded that a dosage of 20 g per plant resulted in optimal growth and yield for eggplant plants. Liquid organic fertilizer is applied simultaneously with watering at a dosage of 1 ml/L, as indicated on the packaging label. Manual methods are employed to control plant pests, such as removing weeds surrounding the plants and physically removing visible pests. Towards the end of the study, numerous eggplant plants were attacked by pests, prompting the use of decis pesticides through spraying. As stated on the packaging, the recommended dosage of 2 ml/L was utilized. Additionally, eggplant plants require support to ensure upright growth and minimize physical damage caused by wind. Stakes are installed 3 weeks after planting to provide the necessary support. Lastly, pasting eggplant plants involves removing water shoots, leaving the fourth and subsequent shoots intact. This practice aims to maintain a balanced nutritional state, shape the plant canopy, and facilitate maintenance tasks.

The fourth phase in the agricultural process is known as harvest. The timing of harvesting mustard and eggplant plants is not synchronized, as it depends on the readiness of the plants for harvesting. Mustard plants that are cultivated outside the panel are harvested at 35 DAP (Harvest Stage Time), whereas those grown under the panel are harvested at 45 DAP. Harvesting mustard greens involves uprooting the entire plant, including its roots. On the other hand, eggplant harvesting is carried out in multiple stages, with intervals of 3-7 days between each stage. The harvested eggplant fruits are easily identifiable due to their vibrant and shiny appearance. The fruit stalk is cut 2 cm above the stem's base to harvest the eggplants using scissors. Eggplant plants cultivated outside the panel are ready for harvesting at 50 DAP, while those grown under the panel are harvested at 65 DAP.

3. RESULT AND DISCUSSION

General conditions of the study

Cultivation activities of mustard greens and eggplants are carried out at the solar panel installation located at Baron Techno Park. The research site, which is very close to Baron Beach, significantly influences the microclimate conditions at the location, such as winds and temperatures that can change at any time during the research activities. The sunlight the plants receives also varies depending on the time and location of the plants (plant rows).

a. At 8:00 a.m.

b. At 10:00 a.m

c. At 12:00 pm

d. At 14:00 pm

Figure 5. Sunlight at different times of the day

Figure 5 shows the varying sunlight received by plants at different times during the research (image data collected in early September 2022). This variation is responsible for the differing growth and yields of mustard greens and eggplants, whether they are located under or outside the panel.

The research findings generally indicate that plants grown outside solar panels exhibit better growth and yield outcomes than those grown under the panels, particularly eggplant plants. This disparity is believed to be linked to the impact of shading on plant growth. It is widely recognized that certain plant species are more tolerant to shade than others. Numerous research studies have been conducted to assess the influence of shading on various plant species across different seasons. The biomass generated through photosynthesis in shade-tolerant and shade-intolerant plants tends to increase as the level of shading decreases (Touil et al., 2021).

Gonocruz et al. (2021) determined that the optimal shading level for rice plants in agrivoltaic systems is between 27-39%, while there is limited literature available on shading requirements for vegetable plants like mustard greens and eggplants. The biomass produced by plants is essential for their growth and development processes, ultimately leading to agricultural products such as leaves in mustard plants and fruits in eggplant plants.

Mustard and eggplant plants are cultivated in polybags arranged in rows with specific spacing. By adjusting the plant spacing, the growth of the plants can be enhanced, leading to improved physical quality of mustard greens. According to Nugraha et al. (2021), optimal plant height and number of leaves can be achieved by maintaining a planting distance of 40x40 cm2 for mustard greens with organic cultivation. Similarly, it is necessary to adjust the spacing between polybags for eggplant plants. The regulation of plant spacing is crucial as it affects the plant's ability to absorb sunlight and CO2. Water and nutrients. When each plant receives an adequate amount of these resources, competition among plants can be minimized. Nainggolan et al. (2019) found that the best yields of eggplants were obtained when the plant spacing was set at 60x70 cm2. In the research conducted, the spacing of 25x40 cm2 for mustard greens and 50x80 cm2 for eggplant was chosen to accommodate the solar panel buildings used.

The research utilized a planting medium of soil and manure in a 1:1 ratio. Incorporating manure into the planting medium enhances the nutrient composition, encompassing both macro and micronutrients. Additionally, manure plays a crucial role in boosting water retention capacity, soil microbial activity, cation exchange capacity, and enhancing soil structure (Anjarwati et al., 2017). This choice was made due to the low fertility levels of the soil sourced from the research site, as indicated by soil sample analysis results (Table 1).

Table 1. Analytical results of soil samples used in the study

Analysis Result	Sample	
	Soil replication 1 (%)	Soil replication 2 (%)
Water content (0.5 mm)	13.712	13.492
Water content (2 mm)	14.783	14.819
C-organik (Walkley&Black)	1.454	1.369
N total (Kjedahl)	0.189	0.183
P_2O_5 (Eks HCl 25%)	0.0287	0.0275
K	0.1728	0.1268

Seeding should be conducted before planting to ensure the production of healthy, adaptable seeds upon transfer to the planting site. The age of the transplanted seedlings plays a crucial role in their adaptability and growth rate. Seedlings that are too young or undersized may result in low adaptability to the environment. In contrast, although larger, those transplanted too late may not have sufficient time during the production stage to acquire optimal environmental conditions, leading to suboptimal outcomes (Setyoaji & Setiawan, 2021). Research findings (Ramli et al., 2017) indicated that seedlings aged 1 week post-sowing exhibited the highest plant height, leaf count, and yield. In the study, mustard seedlings were transferred to polybags when they were approximately 2 weeks old or had 2-3 leaves. Buhaerah & Kuruseng (2016) concluded in their study that the most suitable age for transplanting eggplant plants is 2 weeks after planting. However, in their research, eggplant seedlings were moved to polybags when they were around 4 weeks old or had 4-5 leaves. The appropriate timing for transplanting is influenced by the plant species, variety, environmental factors, and cultivation methods (Ramli et al., 2017).

Growth and Yield of Mustard Crops

Cabbage plants generally thrive well in agrivoltaic systems, although there are slight differences in growth and yield between cabbage plants under the panels and those outside. The analysis of the development and yield data of cabbage plants can be found in Table 2.

Table 2. Growth and yield of mustard under and outside panels

Observation Parameter	Under Panel	Outside panel
Plant height (cm)	36.94 ± 0.5 a	36.22 ± 0.4 a
Number of leaves (pieces)	8.75 ± 0.2 a	8.21 ± 0.1b
Fresh weight of crown (g)	85.28 ± 5.3 a	73.92 ± 3.2 a
Fresh weight of roots (g)	3.52 ± 0.2 a	3.96 ± 0.2 a

Note: figures followed by the same letter in the row show no difference based on the independent T-test.

Table 2 shows that only the average number of leaves exhibits a significant disparity between mustard greens cultivated under and outside the panel. Mustard greens grown under the panels demonstrate a slightly higher number of leaves than those grown outside the panels. However, despite having varying average values, other parameters such as plant height, fresh shoot weight, and root fresh weight do not exhibit statistically significant differences. This result suggests that mustard plants possess a solid adaptability for agrivoltaic systems due to their shade tolerance. Mustard plants can thrive in shaded areas or receive 3-5 hours of sunlight daily. Additionally, they can withstand high temperatures of up to 35°C and temperatures as low as -3°C. These research findings slightly differ from a study conducted by Kumpanalaisatit et al. (2022), which indicated that, overall, the growth of Pakcoy mustard greens outside the panel (control) was superior when compared to those under the panel, considering parameters such as stem diameter, number of leaves, leaf size, and plant fresh weight. However, no difference was observed in terms of plant height. Another study on lettuce plants cultivated using an agrovoltaic system and a control system (not an agrivoltaic system) revealed an equal number of leaves at 30 DAP (hours since treatment). Still, from 37 to 58 DAP, there was a noticeable difference. The control treatment exhibited more leaves than the agrivoltaic system (Zheng et al., 2021).

The growth of mustard plants is more consistent outside the panels than those grown under the panels. As a result, the harvesting process is conducted at different times. Mustard plants outside the panel are harvested earlier, precisely at 35 DAP, while those under the panel are harvested at 45 DAP. The disparity in mustard plant growth between outside and below the panel is illustrated in Figure 6. This discrepancy is believed to be attributed to the amount of sunlight the plants receive. A low-light environment hinders the growth rate of lettuce plants. The number and width of lettuce leaves exhibit variations at different stages of plant development. At 30 DAT, there is no difference in the number of lettuce leaves. However, after 37 DAT, the agrivoltaic system showed a lower number of lettuce leaves than the control group (non-agrivoltaic system). Furthermore, the width of new lettuce leaves demonstrates contrasting outcomes after 44 DAP, with the control treatment displaying superior results compared to the agrivoltaic system (Zheng et al., 2021).

Figure 6. Mustard plants at 30 DAP

The results presented in Table 3 indicate no significant difference in the growth and yield of mustard plants between rows located below the panel. Conversely, Table 4 illustrates variations in the development and yield of mustard plants among rows situated outside the panel, except for the plant height parameter. Notably, mustard plants in row 5 exhibit the most favorable growth and yield outcomes. This observation suggests that row 5 may receive the highest amount of sunlight, as depicted in Figure 7 and Figure 8.

Table 3. Growth and yield of mustard under panel

Observation Parameter	Row 1	Row 2	Row 3	Row 4	Row 5
Plant height (cm)	37.91 ± 1.2 a	36.18 ± 1.1 a	38.69 ± 1.3 a	35.79 ± 0.9 a	36.14 ± 1.0 a
Number of leaves (pieces)	8.75 ± 0.4 a	8.30 ± 0.4 a	9.00 ± 0.4 a	8.40 ± 0.4 a	9.30 ± 0.5 a
Fresh weight of crown (g)	96.70 ± 10.2 a	77.30 ± 14.1 a	91.00 ± 12.1 a	70.00 ± 7.6 a	91.40 ± 14.5 a
Fresh weight of roots (g)	4.50 ± 0.6 a	3.00 ± 0.4 a	3.60 ± 0.7 a	2.70 ± 0.2 a	3.80 ± 0.5 a

Note: figures followed by the same letter in the row show no difference based on the DMRT test at the 5% level.

Table 4. Growth and yield of mustard outside panel

Observation Parameter	Row 1	Row 2	Row 3	Row 4	Row 5
Plant height (cm)	34.85 ± 0.8 a	36.44 ± 1.0 a	36.65 ± 0.7 a	37.71 ± 1.1 a	35.47 ± 0.8 a
Number of leaves (pieces)	7.90 ± 0.3 b	8.40 ± 0.3 b	7.70 ± 0.3 b	7.70 ± 0.3 b	9.35 ± 0.3 a
Fresh weight of crown (g)	54.21 ± 5.4 b	74.87 ± 5.9 a	72.41 ± 6.0 ab	83.22 ± 9.8 a	84.89 ± 6.0 a
Fresh weight of roots (g)	2.67 ± 0.4 c	3.59 ± 0.3 bc	4.03 ± 0.3 b	4.10 ± 0.4 b	5.41 ± 0.4 a

Note: figures followed by the same letter in the row show no difference based on the DMRT test at the 5% level.

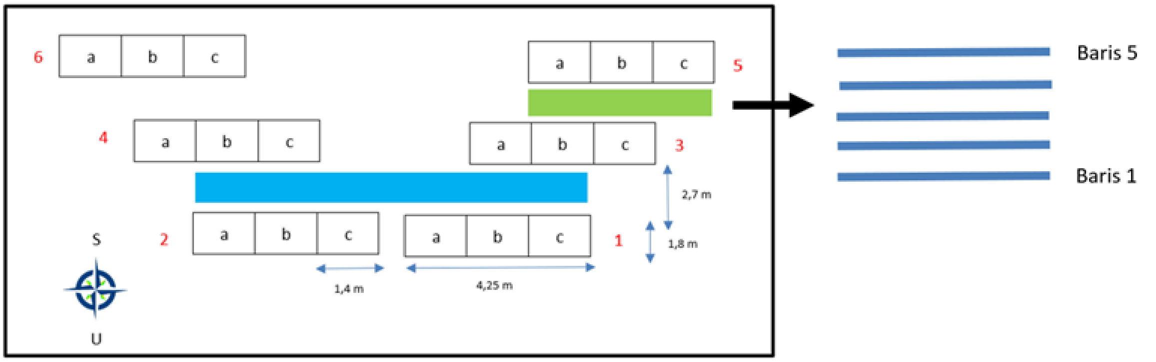

Figure 7. Plan of mustard rows outside the panel

Figure 8. Sunlight obtained by mustard plants outside the panel

The impact of plant row position on tomato plant growth in an agrivoltaic system was observed in a study conducted by Al-Agele et al. (2021). The findings were consistent with previous research, indicating that rows of plants receiving minimal shade exhibited superior growth due to increased sunlight exposure. Kumpanalaisatit et al. (2022) further support this notion, highlighting the direct influence of high-intensity sunlight on plant photosynthesis, particularly in leaf organs. However, it is essential to note that this study's measurement of leaf area parameters was limited to selecting mustard leaf samples without distinguishing between those planted under or outside the panel (Table 5).

Table 5. Sample data of mustard leaf area

	Leaves numbers	Average leaf area (cm^2)	Total leaf area per plant (cm^2)
Plant 1	9	110.78	997.00
Plant 2	7	92.71	648.98
Plant 3	9	107.35	966.12
Plant 4	6	120.74	724.41
Plant 5	4	97.54	390.17
Plant 6	7	130.84	951.86
Plant 7	9	126.83	1141.47
Plant 8	7	120.36	842.55
Plant 9	9	106.52	958.69
Plant 10	9	125.00	1125.00
Plant 11	7	117.72	824.06
Plant 12	5	125.77	628.85
Plant 13	7	108.27	757.90
Plant 14	7	122.11	854.76

Leaf area data is crucial for assessing the photosynthetic activity of plants. Nevertheless, the measurement of plant photosynthetic activity, which is closely linked to plant physiological processes, has not been conducted in this study. Plant photosynthesis is ultimately quantified by measuring the biomass produced by the plant, which reflects the photosynthesis results. According to Weraduwage et al. (2015), leaf area growth plays a significant role in light interception. It is vital in determining plant productivity through various physiological processes, particularly leaf photosynthesis.

Consequently, mustard plants can generally be cultivated using an agrivoltaic system, either under or outside the panels, without adversely affecting their growth and yield. However, mustard plants grown outside the panel exhibit a faster harvesting time than those grown inside the panel. Mustard greens cultivated outside the panel are typically harvested at 35 DAP (hours since transplanting), whereas those grown inside the panel are harvested at 45 DAP.

Eggplant Growth and Yield

Eggplant plants can generally grow well in the agrivoltaic system, although the growth and yield show differences between eggplant plants under the panel and those outside the panel. The results of data analysis on the development and yield of eggplant plants can be seen in Table 6 and Figure 9.

Table 6. Growth and yield of eggplant under and outside panels

Observation Parameter	Under panel	Outside panel
Plant height (cm)	10.99 ± 0.5 b	22.33 ± 1.0 a
Number of leaves (pieces)	6.09 ± 0.2 b	7.98 ± 0.2 a
Fresh weight of crown (g)	6.19 ± 0.2 b	7.57 ± 0.2 a
Fresh weight of roots (g)	0.51 ± 0.1 b	3.39 ± 0.2 a
Plant height (cm)	89.67 ± 18.6 b	674.81 ± 43.3 a

Note: Numbers followed by the same letter in the row show no difference based on the independent T-test.

Figure 9. Eggplant growth at 65 DAP

Hence, eggplant plants exhibit a high sensitivity to shade, as evidenced by growth parameters, and eggplant yields data from areas outside the panel, surpassing those within the panel. Eggplant plants outside the panels receive more sunlight or longer exposure to sunlight than those positioned under the panels. Similar findings have been documented in studies on tomato cultivation (Al-Agele et al., 2021), rice production (Gonocruz et al., 2021), and mustard greens cultivation (Kumpanalaisatit et al., 2022) conducted using agrivoltaic systems. In the case of tomatoes, plants under the panel displayed the lowest fruit yield compared to those in the open as a control group. Rice plants grown under an agrivoltaic system demonstrated satisfactory growth and yields even at shade levels ranging from 17% to 39%. Mustard plants also exhibited enhanced growth and yield in the control treatment (outside the panel) when contrasted with those under the panel. This observation is further supported by Weselek et al. (2019), who noted that solar panels in agrivoltaic systems not only reduce the duration of sunlight exposure for plants but can also impact changes in microclimatic conditions beneath the panels, such as increased air and soil temperatures, particularly in regions with high solar radiation levels. In certain instances, these conditions may have adverse effects on plants, such as diminishing the quality of potato tubers.

The growth and yield of eggplants between the rows inside and outside the panel also exhibit differences (see Tables 7 and 8).

Table 7. Eggplant growth and yield under panel

Observation Parameter	Row 1	Row 2	Row 3
Plant height (cm)	13.14 ± 1.1 a	11.11 ± 0.7 a	8.56 ± 0.5 b
Number of leaves (pieces)	6.67 ± 0.4 a	6.19 ± 0.4 ab	5.36 ± 0.2 b
Fresh weight of crown (g)	6.83 ± 0.4 a	5.90 ± 0.3 a	5.77 ± 0.3 a
Fresh weight of roots (g)	0.97± 0.2 a	0.39 ± 0.2 b	0.17 ± 0.1 b
Plant height (cm)	172.39 ± 41.2 a	69.17 ± 32.1 b	27.44 ± 11. 8 b

Note: Numbers followed by the same letter in the row show no difference based on the DMRT test at the 5% level.

Table 8. Eggplant growth and yield outside panel

Observation Parameter	Row 1	Row 2	Row 3
Plant height (cm)	14.31 ± 0.9 c	23.27 ± 1.2 b	29.93 ± 1.6 a
Number of leaves (pieces)	6.74 ± 0.3 b	8.69 ± 0.3 a	8.63 ± 0.4 a
Fresh weight of crown (g)	7.24 ± 0.3 a	7.52 ± 0.3 a	7.97 ± 0.3 a
Fresh weight of roots (g)	1.89 ± 0.2 b	4.42 ± 0.4 a	3.86 ± 0.3 a
Plant height (cm)	354.11 ± 44.4 b	899.97 ± 78.8 a	770.33 ± 66.3 a

Note: Numbers followed by the same letter in the row show no difference based on the DMRT test at the 5% level.

Tables 7 and 8 indicate that the placement of plants inside and outside the panel significantly impacts the growth and yield of eggplant plants, except for the stem diameter parameter. Eggplant plants in row 1 within the panel exhibited the most favorable growth and yield. Conversely, eggplant plants outside the panel in rows 3 and 2 displayed superior growth and yield compared to row 1. This phenomenon is attributed to the positioning of the plants that receive the highest amount of sunlight (Figure 10). These findings align with previous research on tomato cultivation utilizing an agrivoltaic system (Al-Agele et al., 2021). In the case of tomatoes, they are planted in rows treated as individual plots. Over time, tomato plants in each row exhibit varying growth characteristics. Those in rows receiving more sunlight demonstrate enhanced growth. However, the orientation of the panels in this study differs from that used in the tomato cultivation study (Al-Agele et al., 2021). Specifically, the height of the panels on the southern side was more significant than on the northern side in this study, whereas the opposite was confirmed in the tomato plant study. Consequently, the southern rows exhibited superior growth and yield in this study, whereas in the tomato study, the northern rows showed better growth and yield.

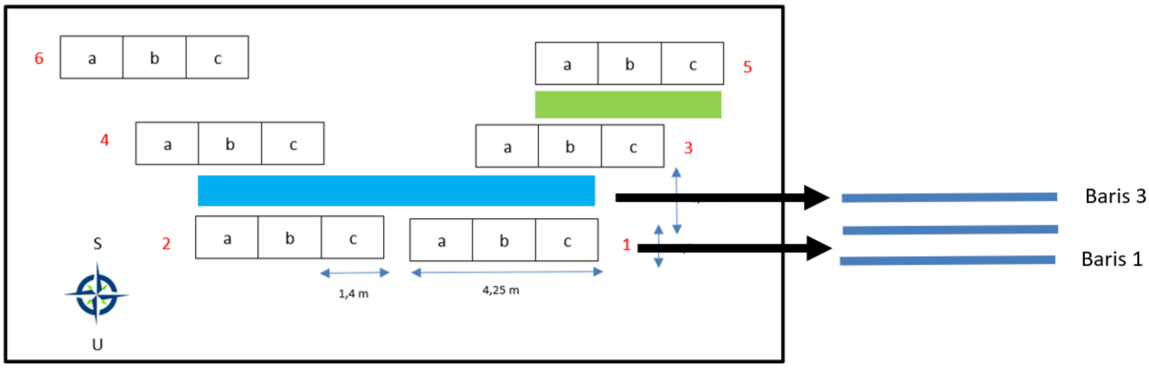

Figure 10. Row position of eggplant plants inside and outside the panel

The reduction of sunlight radiation beneath the panels is highly dependent on the sun's altitude during each season and the position and configuration of panels in agrivoltaic systems, such as the tilt angle, size, and spacing between panels. The solar panel layout can cause uneven and varying shading throughout the day, depending on the sun's altitude. Reducing panel density by adjusting wider panel spacing can increase incoming light. A panel row spacing of 3.2 meters can increase incoming sunlight by 73% (Weselek et al., 2019).

At the end of the research, around

early October 2022. almost all eggplant plants were infested by the flea beetle pest (Epilachna spp), also known as the outing-outing pest. The pest attacks the leaves and fruits, resulting in the eggplant fruits being unable to be harvested (Figure 11c). The pest causes damage to the plants, resulting in decreased production due to disrupted plant growth and development. The flea beetle is one of the main pests that attack eggplant plants. The beetle damages the plants by eating the epidermis layer on the underside of the leaves, leaving the upper part intact so that the affected leaves become skeletonized and dry like a net (Figure 11b) (Apriliyanto & Setiawan, 2019). This pest is active in attacking in the morning; its activity decreases during the day, becomes active again in the afternoon, and reduces activity at night (Arsi et al., 2022). The pest infestation is suspected to be due to the eggplant plants growing more extensive and not being thinned out, causing the plants to overlap and increase humidity around the plants, which can attract pests and diseases to attack the plants. The intensity of pest attacks can be influenced by planting distance, plant maintenance, plant age, and environmental conditions such as temperature and humidity (Arsi et al., 2022).

a b c d

Figure 11. Pest infestation on eggplant plants at the end of the study

Typically, eggplants have the potential to be cultivated using the agrivoltaic system, either within or outside the panel structure. However, it is essential to note that the growth and outcomes of eggplants vary depending on their placement. Eggplants planted outside the panel are typically ready for harvest earlier, precisely at 50 DAP (Harvest Start Time), whereas those grown within the new panel structure commence their harvest at 65 DAP.

4. CONCLUSION

In an agrivoltaic system, both mustard and eggplant plants can be grown. Mustard plants can be positioned under or outside the panels without impacting their growth and yield. On the other hand, while eggplant plants can be placed inside the panel, their growth and yield may not be as optimal as when they are placed outside the panel

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