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Study the Application of Automatic Unpowered Fertigator (FONi) in Eggplant (Solanum melongena) Cultivation

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Abstract

Water scarcity, intensified by climate change and pollution, necessitates innovative irrigation approaches to sustain agricultural productivity. The Automatic Unpowered Fertigator (FONi) represents a solution that integrates automation without electricity, using evapotranspiration-driven subsurface irrigation to deliver water and nutrients directly based on plant demand. Unlike conventional systems, FONi operates entirely without external energy input, offering a low-cost and sustainable alternative for smallholder farmers. Previous applications in various crops have demonstrated significant water savings and increased productivity, indicating its strong potential as a scalable technology for resource-limited agriculture.This study evaluated the performance of FONi in cultivating four eggplant varieties under greenhouse conditions in Bekasi City, an area facing increasing competition for water resources. Over a 118-day growing period, plant growth, water use, crop coefficients (Kc), and productivity were monitored. Results showed Kc values ranging from 0.1 to 1.8, reflecting dynamic water demand throughout plant development. The long purple variety attained the greatest height (99.8 cm), while pondoh and white varieties achieved higher water productivity (up to 4.0 g/L) and land productivity approaching 1,120 g/m². Total irrigation water use was 1,329.3 liters, with an overall application efficiency of 98.9%. These findings demonstrate that integrating FONi with appropriate crop selection provides an efficient and sustainable strategy to optimize water use and enhance yield, supporting precision agriculture and climate-resilient food systems in drought-prone regions.

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1. Introduction

Water scarcity remains a critical constraint in agricultural production because crop water requirements are closely linked to irrigation practices. Therefore, improving irrigation efficiency is essential for reducing water loss and sustaining crop yields. Conventional surface irrigation typically achieves only 30–40% efficiency, whereas micro-irrigation methods, such as drip, sprinkler, and computer-based smart irrigation, may reach 80–90% (Rijsberman et al., 2006; Christen et al., 2006;

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Kuslu et al., 2016). However, adoption among smallholder farmers has been limited owing to high operational costs and dependence on electricity, which undermines system reliability during power disruptions (Rejekiningrum & Saptomo, 2015).

The Automatic Unpowered Fertigator (FONi) offers a novel alternative for addressing these challenges. FONi integrates automation without electricity, relying on evapotranspiration-driven subsurface irrigation to supply water and nutrients directly, according to plant demand. Previous studies have demonstrated the effectiveness of this method in enhancing water-use efficiency across a range of crops. In lettuce, FONi achieved water savings of up to 92% with productivity reaching 10.15 kg/m^3 (Eprida et al., 2024), whereas in rice cultivation, FONi increased water productivity to 6.45 kg/m^3, or 2.7 times higher than conventional systems, enabling up to three harvests in one season (Safitri et al., 2024). Muharomah et al. (2023) further emphasizes that FONi can achieve irrigation efficiencies approaching 100% without external energy input, highlighting its potential as a sustainable and scalable irrigation solution.

Eggplant (Solanum melongena L.) was selected as the focus of this study because of its widespread consumption, affordability, and significant health benefits. It is also highly adaptable to the tropical climate of Indonesia (Ludihargi et al., 2019). Among its many varieties, pondoh, white, long purple, and gelatik were chosen based on their high economic value, stable market demand, and prevalence in local cultivation. These four varieties also exhibit distinct differences in size, shape, and agronomic requirements, providing a broader basis for assessing irrigation performance under diverse conditions. By selecting varieties widely cultivated by farmers, the findings of FONi application are expected to be more relevant, applicable, and readily adopted in practical farming.

2. Material and Methods

2.1 Location and Time

The research was conducted at the Balai Teknik Irigasi greenhouse in Bekasi City, West Java, with coordinates -6.255627, 107.001323. The greenhouse at the research site measures 15 x 12 meters with a height of 4 meters. The greenhouse used in this study was a structure covered with a polyethylene (PE) film. This type of covering provides an effective barrier against rain and wind while maintaining adequate humidity and temperature for plant growth, making it highly suitable for experimental and small-scale agricultural applications in the future. The research period will begin in September 2024 and end in February 2025.

2.2 Material

The equipment used in this study was a laptop as a means of collecting and processing data and running various software programs. The software used for data processing in this study included Microsoft Office and SketchUp software. Other tools used were an automatic weather station placed

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inside the plant house and Ezviz CCTV used to monitor the growth and security of the array. The materials used included various eggplant vegetable seeds, growing medium, 35 x 40 cm polybags, and components for the FONi system, such as an L-shaped table, buckets, ½-inch PVC pipes, a 200-liter tank as a reservoir, seedling trays, and pipe connectors.

2.3 Design

The study was conducted in a greenhouse equipped with a FONi system consisting of 48 pots and 2 seedling trays, as shown in Figures 1 and Figure 2. A tank was used as a reservoir and was equipped with an automatic valve on the first control tank to regulate the water level. The pots were arranged using ½-inch PVC pipes in parallel to ensure an even water flow to all pots. Each of the 4 pipe rows was connected to 12 pots containing growing medium in polybags. On the right side of the tank was the second control tank and seedling table, which supported two seedling trays with a parallel water distribution system.

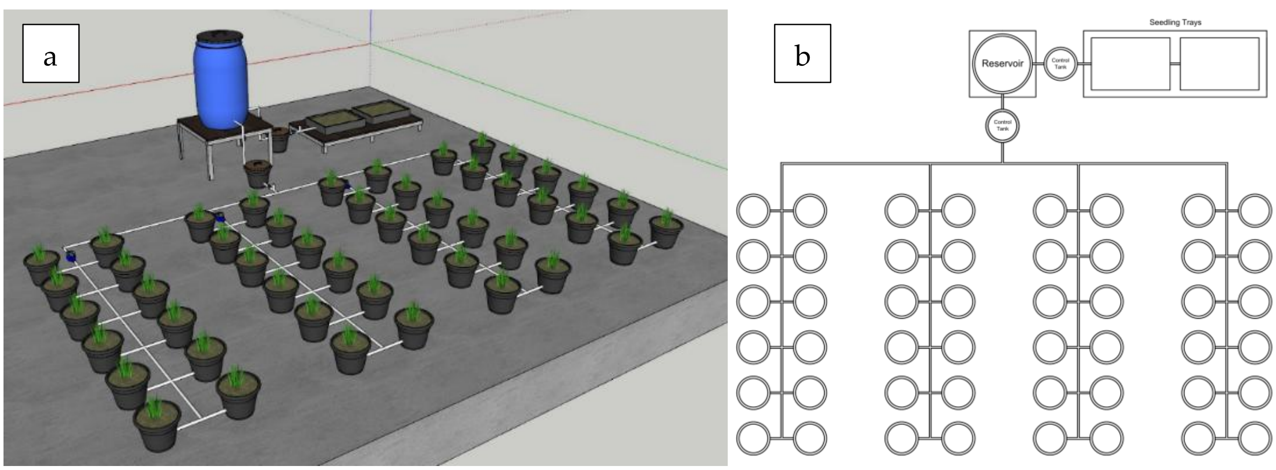

Figure 1. Design of FONI at Balai Teknik Irigasi, Bekasi. (a) Isometric view of the FONi design, (b) 2D view of the FONi design.

2.4 Eggplant Cultivation

Eggplant cultivation lasts approximately 118 days, beginning with the selection of healthy, high-quality seeds. Seeds were sown 1–2 cm deep in a shaded germination medium until they sprouted. Once the seedlings develop 3–4 true leaves, they are transplanted into polybags placed in pots or containers. The FONi system automatically supplies water, thereby eliminating the need for manual irrigation. Organic liquid fertilizer was applied periodically through the reservoir tank, and weeds were removed regularly to prevent nutrient competition. Pests and diseases are monitored and controlled using organic pesticides. After 60–80 days, the plants begin to flower and bear fruit. Fruits were harvested when they reached full size and had shiny skin using a knife or scissors. With proper maintenance, eggplants can produce fruits for several months before their productivity declines.

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2.5 Data Colleting and Processing

Data processing began by calculating evapotranspiration values during the study period. Climate data were collected every 10 min from an AWS installed inside the greenhouse. Evapotranspiration is a combination of evaporation and transpiration, which are difficult to separate because they occur simultaneously (Allen et al., 1998). The Hargreaves method is a commonly used method for calculating ETp. Adlan et al. (2021) state that this method approximates the Penman-Monteith model, which is recommended by the FAO for evapotranspiration calculations. According to Hargreaves (1985), ETp values were calculated using a formula based on air temperature and solar radiation. Potential evapotranspiration (ETp) values were calculated using the Hargreaves method, as shown in Equation 1.

$$ETp = 0{,}0023\sqrt{Tmax - Tmin}\,(Tavg + 17{,}8)Ra \tag{1}$$

Where ETp is evapotranspiration (mm), Tmax is maximum temperature (°C), Tmin is minimum temperature (°C), Tavg is average temperature (°C), and Ra is extraterrestrial radiation (MJ/(m^2/day)). The Hargreaves method was chosen because it is a commonly used method for calculating ETp and is similar to the Penman-Monteith model, which is recommended by the FAO for evapotranspiration calculations (Adlan et al., 2021).

The height of the eggplant plants of the four varieties was recorded at each observation time. Water consumption was also observed using a water meter on the FONi system. The data were then presented in graphical form and plotted against time to obtain the water consumption rate as a representation of the actual evapotranspiration (Maclean et al., 2012). After obtaining the actual evapotranspiration value, the crop coefficient values for the eggplant varieties were calculated using Equation 2 as follows:

$$Kc = \frac{ETa}{ETp} \tag{2}$$

Where Kc is the crop coefficient, ETa is the actual evapotranspiration value (mm), and ETp is the potential evapotranspiration value (mm). The obtained Kc value was then compared with those reported in previous studies. Based on the eggplant crop yield data, water productivity and land productivity values can be obtained using Equations 3 and 4, as follows:

$$WP = \frac{W}{V} \tag{3}$$

$$LP = \frac{W}{A} \tag{4}$$

Where WP is water productivity (g/l), W is eggplant production weight (g), V is irrigation water volume (l), LP is land productivity (g/m2), and A is planting area (m2). This calculation is necessary

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because both are indicators of efficiency in the use of key resources in agriculture, namely water and land.

3. Results and Discussion

3.1 Environmental Parameters

The environmental parameters analyzed in this study included climate data, such as temperature, humidity, and solar radiation, which were obtained from an automatic weather station (AWS) located inside the greenhouse. The temperature and humidity during the planting period are shown in Figure 2.

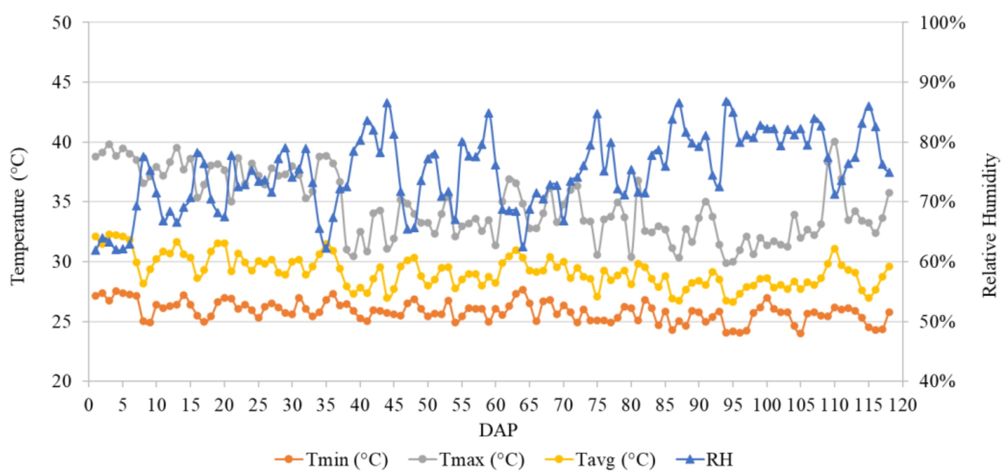

Figure 2. Temperature and relative humidity inside the greenhouse at 118 DAP.

Based on Figure 2, the temperature and humidity fluctuated throughout the growing season. The average daily temperature during the 118 DAP period was 29.2°C, with a minimum of 25.8°C and a maximum of 34.6°C. Compared to the optimal temperature range for eggplant growth (22–30°C; Lardi et al., 2022), these conditions were generally within the tolerance limit. However, the frequent exceedance of 30°C indicates potential heat stress, which can disrupt key physiological processes, such as photosynthesis, pollination, and fruit formation (Santhiya et al., 2019).

The relative humidity (RH) inside the greenhouse ranged from 62% to 87% and averaged 75%. A clear inverse relationship was observed between temperature and humidity; when the temperature increased, the RH decreased. This aligns with the physical principle that warmer air can hold more water vapor, thus lowering the relative humidity if the moisture content remains constant (Hao & Lu, 2022).

As shown in Figure 3, solar radiation (Ra) and potential evapotranspiration (ETp) also varied over time. The average solar radiation was 8.12 MJ/m²/day, and the mean ETp value was 1.1 mm/day, reflecting the dynamic environmental conditions inside the greenhouse. These variations directly influence plant water demand and demonstrate how the FONi system effectively adjusts the irrigation supply to maintain stable moisture conditions. By automatically responding to changes in radiation and temperature, the FONi system helps optimize water use and supports consistent plant growth, despite environmental fluctuations.

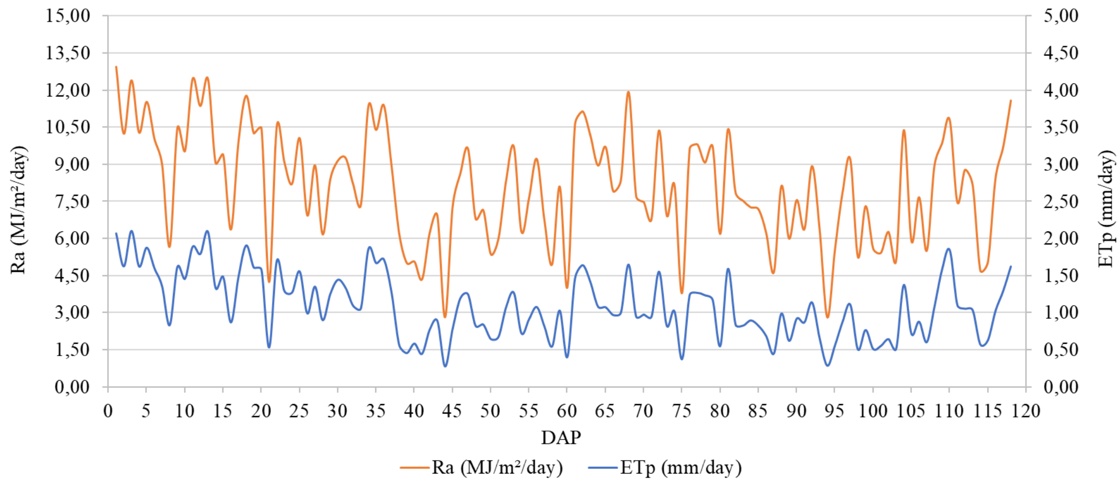

Figure 3. Solar radiation and potential evapotranspiration for 118 DAP.

3.2 Eggplant Growth

The growth of eggplant plants in this study was observed through morphological parameters in the form of changes in their height. Plant height was used as an indicator to assess physical growth during the planting period. This parameter reflects the rate of vertical growth and plant vigor over time. The changes in eggplant plant height during the 118 days after planting are presented in Figure 4.

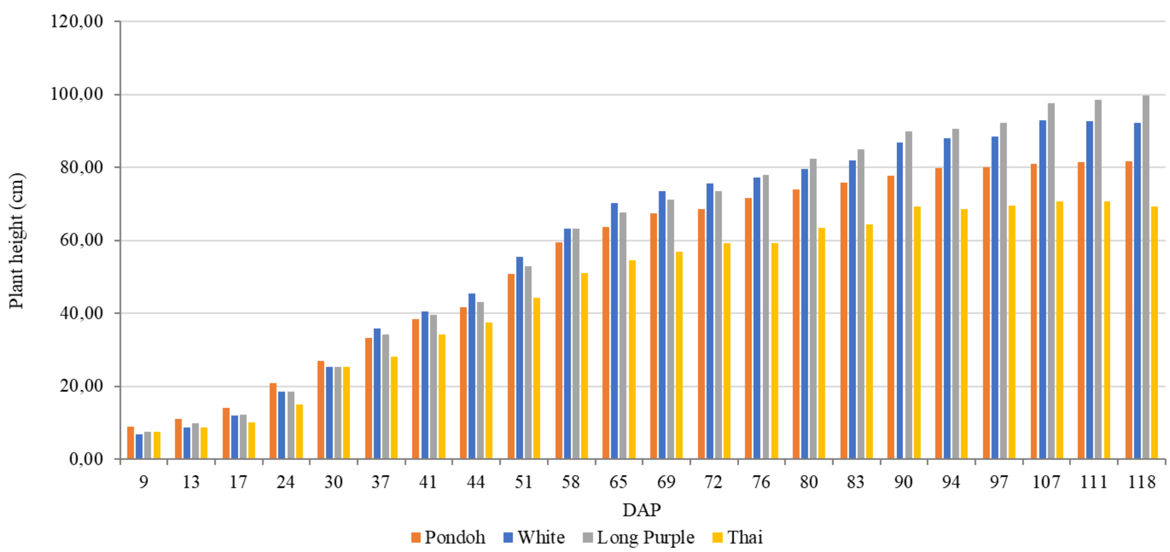

Figure 4. Plant height growth of eggplant over 118 days.

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The graph in Figure 4 shows the differences in growth rates among the four eggplant varieties: pondoh, white, long purple, and Thai. Overall, all four varieties experienced an increase in their plant height over time. The graph shows that the long purple eggplant had the highest plant height throughout most of the observation period, followed by the white eggplant. This indicates that these two varieties have faster growth and relatively better plant vigor than the other varieties. Conversely, Thai eggplants tended to have the lowest growth rate compared to the other varieties. The fastest growth phase occurred between 24 and 72 days after planting (DAP). After that, the growth rate began to slow down, particularly in the Thai eggplant, which appeared to stagnate. These differences indicate that each variety has distinct growth characteristics.

Pondoh eggplant plants showed fairly stable height growth, reaching a height of 82 cm at 118 DAP. The height of these plants at 50 DAP was recorded as 51 cm, indicating fairly good growth during the vegetative phase. These results can be compared with those of study by (Sari Thesiwat et al., 2024), who reported an average plant height of approximately 45 cm at the first harvest age of 50 DAP. The plant height of the white eggplant at 56 DAP was 63 cm. This growth is classified as moderate and indicates that the plants were still in the vegetative growth phase when compared to the results of the study by (Vonnisye et al., 2022), where the height of white eggplant plants at the same age reached 78 cm.

The height of the purple eggplant plants at 58 days after planting was 63.27 cm. This value indicates fairly good vegetative growth, although it has not yet reached its maximum potential compared to the results of other studies. In a study by (Abdul Haris et al., 2024), purple eggplant plants reached a height of 87.4 cm at 60 DAP harvest age. The height of the eggplant plants at 90 DAP was recorded as 69.31 cm. This value indicates fairly good and stable growth, considering that this variety is known to have a shorter stature than other eggplant types. When compared to the literature, the growth range is between 60–80 cm (Caroline Bates, 2025). This indicates that the data graph remains within the ideal range commonly observed in cultivation practices. To understand the growth characteristics in greater depth, modeling is needed to determine the growth rate and estimate the maximum height that a plant can reach. The results of the plant height modeling for the four eggplant plants are presented in Figure 5.

The graph in Figure 5 shows the results of modeling the growth of various eggplant plants using the Verhulst model. The blue line represents the plant height growth curve generated by the model, and the orange dots indicate the actual measurement data. The dotted line shows the plant growth rate in cm/day. In general, all varieties exhibited a sigmoid growth pattern, characterized by an initial slow growth phase, a growth phase, and a deceleration phase until reaching the saturation point. The growth model effectively captures this dynamic, as evidenced by the close alignment between the model results and measured data. Overall, all varieties showed a gradually increasing growth trend at the beginning of the observation period and begin to experience accelerated growth at 20 DAP. The

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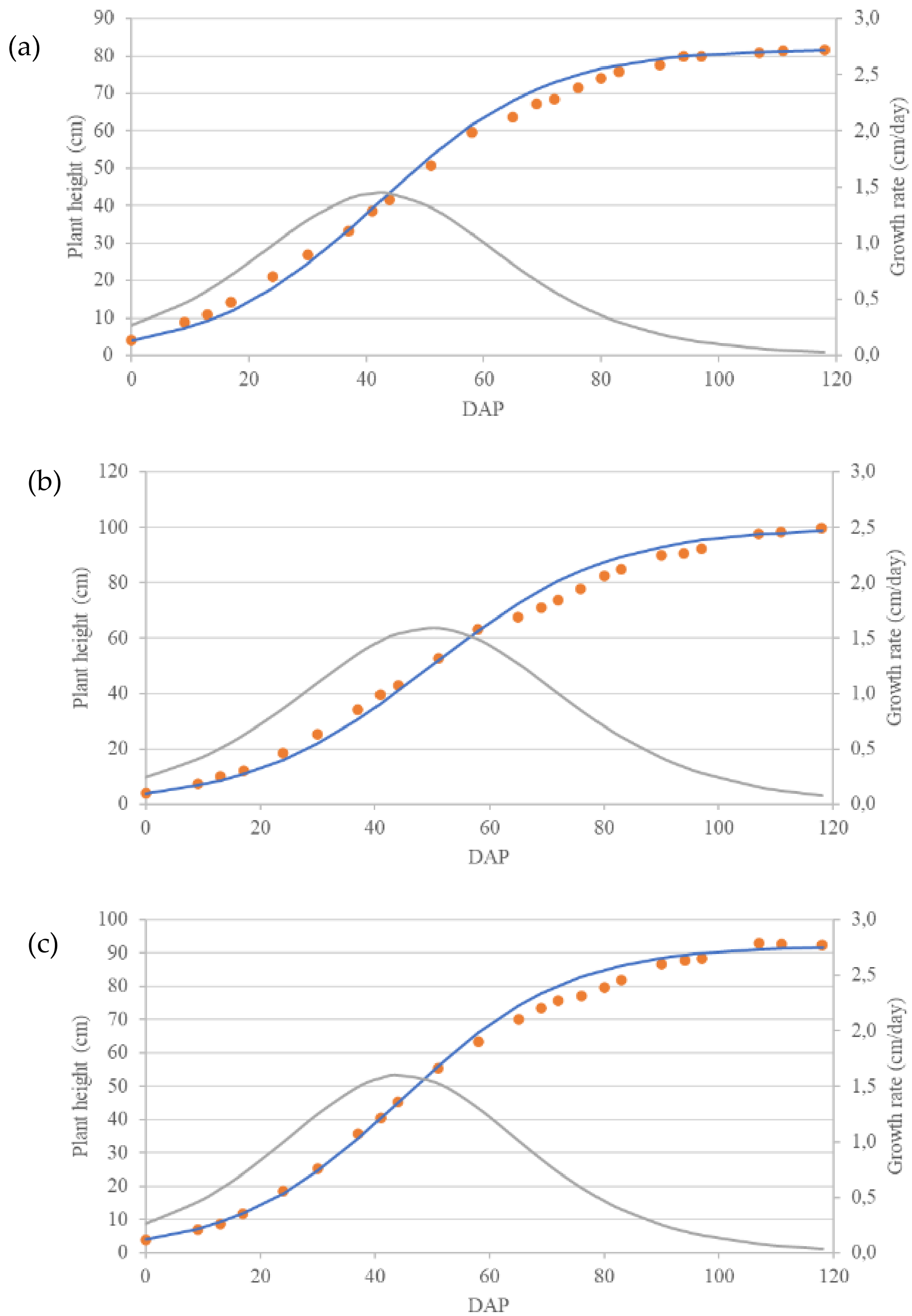
growth rate graphs for each eggplant variety showed that the peak growth rate occurred between 40–50 DAP. White and long purple eggplant plants had the highest maximum growth rate of 1.6 cm/day, while the lowest maximum growth rate occurred in Thai eggplant plants with a value of 1.18 cm/day.



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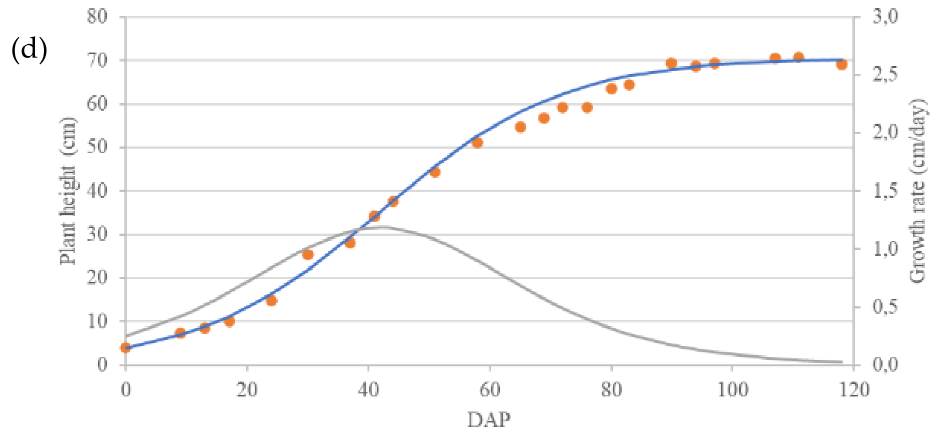

Figure 5. Graph of Plant height modeling results. (a) Pondoh eggplant, (b) White eggplant, (c) Long purple eggplant, (d) Thai eggplant.

3.3 Water Comsumtion

Plant water consumption plays an important role in optimal growth and plant production. The amount of water required by plants fluctuates during the growing season, influenced by growth stage and environmental conditions. Eggplant growth was monitored over a period of 118 days, starting from transplantation. During this period, measurements of water consumption for eggplant growth were conducted. The results of the daily and cumulative water consumption measurements are shown in Figure 6.

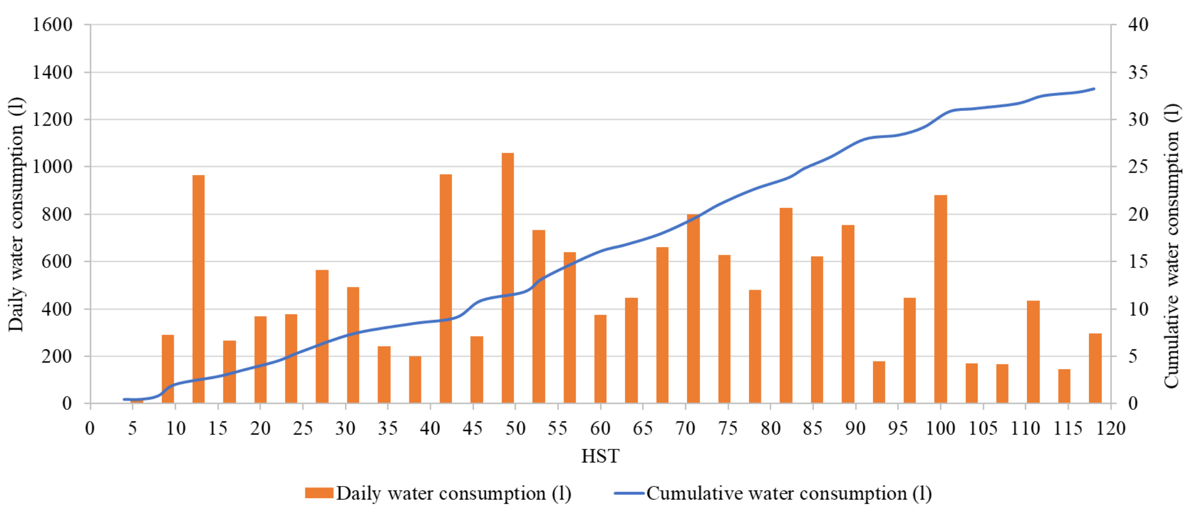

Figure 6. Water consumption for 118 DAP.

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Based on the graph in Figure 6, it can be seen that the amount of water absorbed by plants each day varies. The peak water consumption was recorded on day 53, with a volume of 26.4 L. The cumulative water consumption continued to increase over time, reaching a total of 1,329.3 liters over 118 DAP. In a study using drip irrigation, Abdrabbo et al. (2010) recorded a water requirement for the same number of plants was recorded at 5,074.08 L. This difference shows that this study was able to reduce water requirements by 73.8%, so the method applied can be said to be more efficient in the use of water resources. At the end of the planting period, 15.2 liters of water was not absorbed by the plants. Therefore, the application of FONi in this study resulted in an effectiveness rate of 98.9%. To provide a more informative visualization, the water consumption rate data previously displayed in a bar chart were converted into a scatter plot, with the addition of a trend line to illustrate the general pattern of water use during the growth period. The water consumption rate graph is shown in Figure 7.

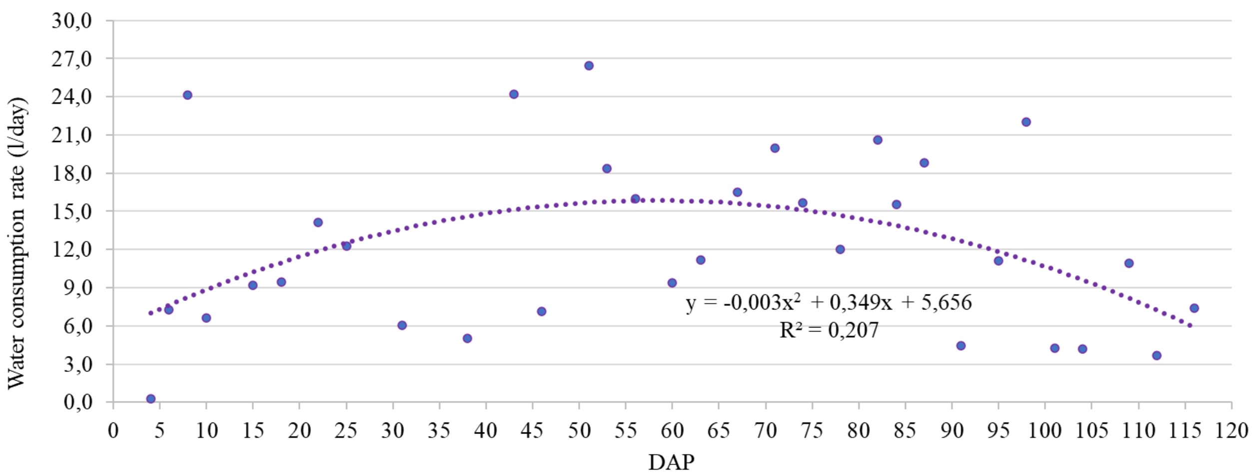

Figure 7. Water consumption rate at 118 DAP.

Based on Figure 7, a parabolic trend line was obtained to describe the relationship between the water consumption rate of the eggplant plants and time (DAP). The curve shows that the water requirements of plants change dynamically throughout the growth period. In the early phase, water use is low because the plants are still small, and the root system is not well developed. As plants enter the vegetative and generative phases, their water demand increases sharply owing to higher biomass, active physiological processes, and fruit formation. Toward the end of the growing season, water use declines as growth slows and harvest approaches. This pattern reflects the typical characteristics of plant growth, which generally follows a downward-opening parabola. The corresponding equation is presented in Equation 5:

$$V(t) = -0.001t^3 + 0.194t^2 + 2.209t + 25.575 \quad (5)$$

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Equation 5 can be used to estimate plant water requirements for the following days, with $V(t)$ as the volume of irrigation water (l) and t as time (DAP). To obtain the equation for the rate of water consumption, the first derivative of the third-order polynomial equation describing the total water consumption over time is taken. This derivative mathematically shows the rate of change in water consumption per unit of time. The equation for the rate of water consumption is shown in Equation 6.

$$\frac{dV}{dt} = -0.003t^2 + 0.387t + 2.209 \quad (6)$$

Where dV/dt represents the rate of irrigation water consumption and t is time (DAP). The quadratic form of this equation indicates that water use changes over time rather than remaining constant over time. In the early growth phase, water consumption gradually increases as plants grow, and their water needs rise. This rate eventually reaches a peak and then declines as plant growth slows, forming a downward-opening parabolic curve.

The water consumption pattern observed in this study aligns with the findings of Allen et al. (1998), who noted that plant water demand increases during the vegetative to early generative phase and decreases toward the harvest. The increase is due to a larger leaf area and higher metabolic activity, while the decline occurs as growth slows and the canopy begins to age.

3.4 Crop Coefficient

Plant water requirements play a crucial role in determining efficient and sustainable irrigation strategies for crops. One of the main indicators for determining these requirements is the crop coefficient (Kc), which is the ratio of actual evapotranspiration to potential evapotranspiration. The Kc value can vary depending on the stage of plant growth and is influenced by the environmental conditions. Therefore, understanding the dynamics of Kc changes throughout the plant life cycle is essential for optimal water management. The Kc values for the various types of eggplant over 118 days after planting are shown in Figure 8.

Based on the graph in Figure 8, the Kc values in the early stages of growth were relatively low. At 0–30 DAP, Kc was in the range of 0.1 to 0.4, reflecting low water requirements due to undeveloped canopies. Subsequently, Kc increased sharply and reached a peak of 1.8 at 60 DAP, marking the vegetative growth phase and the onset of the generative phase, where water requirements were at their highest. After this phase, the Kc value began to decrease gradually, ranging from 0.4 to 1.2 during the mid-to-late growth phase, and finally dropped to approximately 0.2 near 118 DAP. This decrease reflects the reduced water requirement as the physiological activity of the plant declines toward the end of its life cycle. The Kc values obtained are consistent with those reported by (Howell, 2001), where eggplant exhibited Kc values of 0.2–0.5 from 0 to 30 DAP, peaked at 1.9 at 60 DAP, and then declined toward harvest

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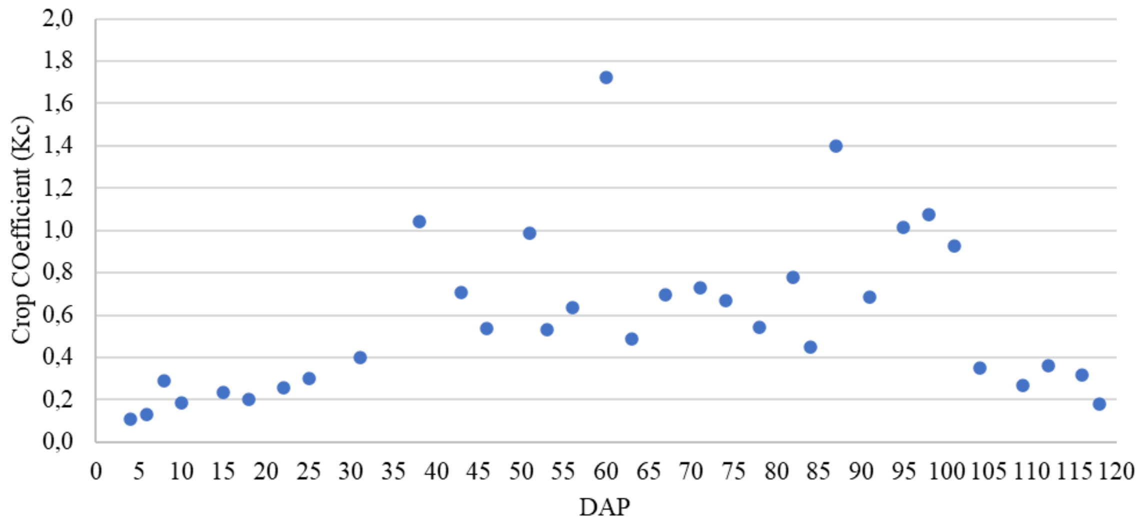

Figure 8. Crop coefficient of eggplants at 118 DAP.

3.5 Antioxidant activity of green coffee beans as influenced by fermentation intensity

Water productivity measures the yield produced per unit of water used, which is crucial under limited water availability (Farida et al., 2019). Similarly, land productivity reflects the efficiency with which land is utilized to produce biomass or yield. In this study, water productivity was 4.0 g/l for pondoh eggplant, 3.6 g/l for white eggplant, 0.7 g/l for long purple eggplant, and 0.75 g/l for Thai eggplant. The corresponding land productivity values were 1100 g/m², 1120 g/m², 238 g/m² and 173 g/m², respectively. According to Kadar et al. (2016) and Rahmat Rukmana (2006), eggplant land productivity in Indonesia typically ranges from 1000–3000 g/m². The productivity of pondoh and white eggplants falls within the lower end of this range, suggesting a performance close to the national standards. In contrast, long purple and Thai eggplants showed much lower productivity, possibly due to varietal differences, environmental stress, or suboptimal adaptation to greenhouse conditions.

4. Conclusion

The application of FONi technology to four eggplant varieties showed significant differences in growth parameters, water consumption, and productivity. The long purple variety had the highest average plant height of 99.8 cm, but this was not accompanied by high water or land productivity. This indicates that plant height does not always correlate with the crop yield. Conversely, the pondoh and white varieties, despite being shorter in size, produced water and land productivity of 4.0 g/L and 3.6 g/L, and 1,100 g/m² and 1,120 g/m², respectively, which are close to the national standard. The Kc value ranged from 0.1 to 1.8, following the pattern of plant water requirements from the early growth phase to the harvest phase. During the 118 DAP, the total irrigation water usage of 1,329.3 liters showed that FONi was able to distribute water proportionally according to plant requirements, with a water-use efficiency of 98.9%. These findings confirm that selecting the right variety, when combined with FONi technology, can be an efficient strategy for optimizing water use and increasing land productivity amid water scarcity.

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