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GROWTH AND YIELD PRODUCTION OF PAKCOY AS INFLUENCED BY ARTIFICIAL LIGHT IRRADIATION

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***Abstract**. Artificial light in indoor plant production is still a challenge related to the amount of electrical energy used, such as in the Pakcoy plant. The Pakcoy plant has nutritional and economic value and is usually used as a research indicator plant. This study aimed to determine the effect of artificial light irradiation on the growth and yield of Pakcoy plants. The research was conducted in a plant factory in an indoor hydroponic system, with LED light of 100 umol/m^2/s as a light source for the growth of Pakcoy plants. The artificial light irradiation length treatment consisted of 4 levels, namely 12 hours/day, 16 hours/day, 20 hours/day, and 24 hours/day. The most significant growth, yield, and content of vitamin C in Pakcoy plants were obtained in maximum artificial light exposure for 24 hours/day, and the highest protein content was obtained in the long irradiation treatment for 16 hours/day.*
***Keywords:** artificial light; irradiation; pakcoy; plant factory*

1. Introduction

Pakchoy (*Brassica rapa Subsp Chinensis*) is one of the Brassica species that have important nutritional content (Cocetta *et al*., 2017) and high economic value (Egorova *et al*., 2021) (Tan *et al*., 2020). These plants are often used as plant models in the research and development of production technology in modern agriculture (Mickens *et al*., 2019) (Tan *et al*., 2020) (Harun *et al*., 2019).

Plant production technology in modern agriculture is able to guarantee high crop production even in uncertain environmental conditions (Paradiso & Proietti, 2022), such as artificial light technology in the plant factory system (Fan *et al*., 2020) (Viršilė *et al*., 2019) (Pennisi *et al*., 2020). Light adequacy, both quantity (intensity and duration of irradiation) and quality (wavelength) in plant factory systems such as greenhouse and growth chambers are key parameters for indoor plant production (Son *et al*., 2016) (Lu *et al*., 2020) (Fan *et al*., 2020) (Paradiso & Proietti, 2022).

Artificial light technology for optimizing plant production was developed from various types of lamps and adapted to cultivated plants (Zhang *et al*., 2020). Artificial light sources, such as light-emitting diodes (LEDs), are used to accelerate plant growth in indoor plant production systems (Harun *et al*., 2019) (Zou *et al*., 2020), especially in a controlled environment/microclimate. Therefore, to obtain superior plant yields, it is necessary to formulate an appropriate artificial light quantity (intensity and irradiation) (Son *et al*., 2016) and artificial

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light quality (Lobiuc *et al*., 2017).

The length of irradiation directly affects plant morphology, such as in the formation of plant biomass (Liu *et al*., 2022). In the production of spinach plants with LED technology, the length of irradiation is a lighting factor that has more influence on plant biomass, such as fresh weight, dry weight, and plant length, compared to the light intensity and wavelength (Zou *et al*., 2020). The long irradiation treatment also affects the nutritional content of plants, such as sugar and protein content in the Brassica microgreen production (Liu *et al*., 2022).

The use of artificial light in indoor plant production with optimal irradiation time is expected to produce quality plant yields and save electrical energy. Therefore, this study focused on the long-term formulation of artificial light irradiation with LED technology on Pakcoy plants. This study aimed to determine the effect of different length of irradiation on the growth, production, and nutrition of Pakcoy plants on artificial light technology.

2. Methods

2.1. Experiment Design

The experiment was conducted at the Control System Laboratory of Cilacap State Polytechnic, Indonesia, from August to December 2021. The experimental site was characterized by an indoor micro-climate with temperatures of 28^{o}C to 33^{o}C and humidity of 60% to 80%. The location was at an altitude of 3 meters above sea level, and astronomically it was at 7^{0}43’04” South Latitude and 109^{0}01’15” East Longitude.

This research was a single-factor study in the form of LED irradiation duration, which consists of 4 levels of treatment, namely 12 hours/day, 16 hours/day, 20 hours/day, and 24 hours. Pakcoy plant production was carried out in a mini plant factory with artificial light as a light source, with a size of 100 cm x 45 cm x 60 cm and a plant capacity of 15 plants per shelf, as shown in Figure 1. The plant seeds used are seeds that are sown for nine days with three true leaves. The environmental design was set as Randomized Complete Design with three replications so that each shelf is randomized, not placed sequentially.

The plant factory technology was in the form of indoor hydroponic cultivation using the DFT (Deep Flow Technique) system. In this system, plant roots get an adequate water supply and nutrients simultaneously and through a recirculation system, with a maintained nutrient solution concentration of 1200 ppm. In addition, the DFT model of this system provides sufficient aeration for plant roots because plant roots are not entirely submerged in nutrient water. This plant factory was also equipped with input and output fans on each shelf to keep the air temperature from getting too hot caused by the irradiation of the plant lights.

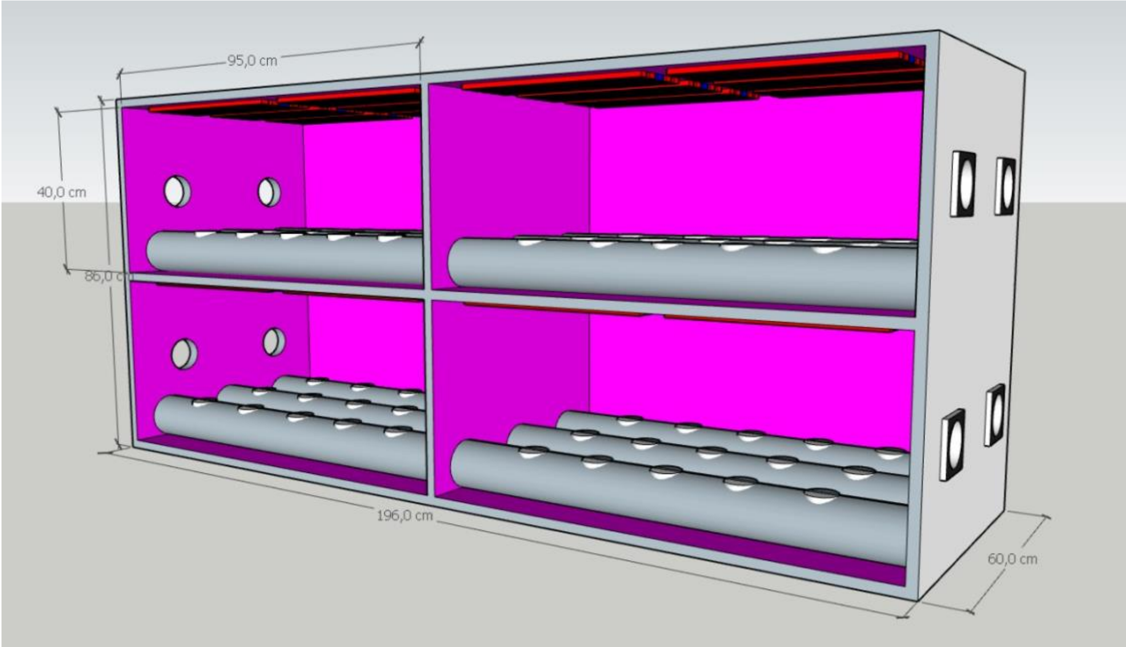

Figure 1. Mini Plant Factory With Artificial Light

2.2. Artificial Light Design

This plant factory is equipped with artificial light technology as a substitute for sunlight. The artificial light source used is the LED lamp. The ratio of red and blue light in this chamber is 4:1, as shown in Figure 2. The control of the light intensity on each lamp and the length of irradiation time are regulated using a microcontroller and a Pulse Width Modulation (PWM) driver, as shown in Figure 3.

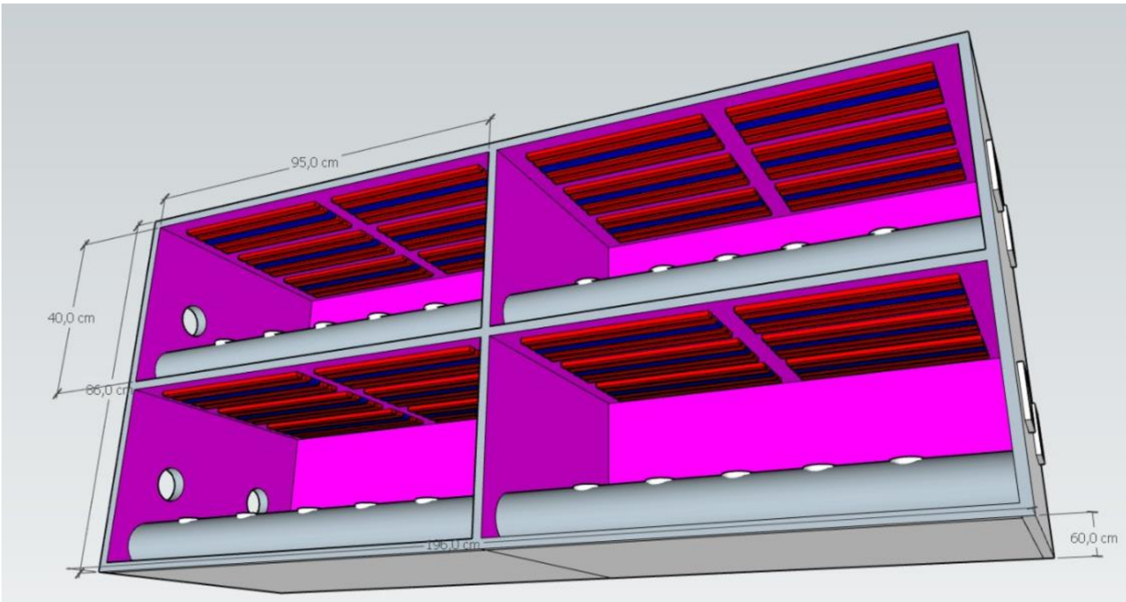

Figure 2. LED lamps placement design of on mini plant factory LED Panel

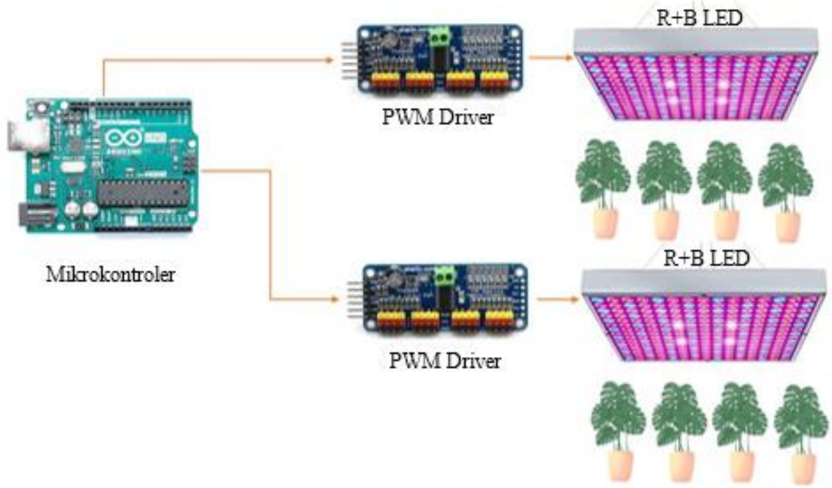

Figure 3. Controller Design for Plant Production Chamber

This system uses the Arduino Uno microcontroller to adjust the intensity of artificial light via the PWM Driver. Meanwhile, automatic irradiation settings use Real Time Clock (RTC) with four levels of irradiation treatment, namely 12 hours/day, 16 hours/day, 20 hours/day and 24 hours. The LED lights turn on with the light intensity and duration of irradiation according to the set point, which is 100 µmol/m^2/s, and four levels of irradiation treatment, where the microcontroller will set the PWM driver.

The artificial growth light used is LEDs light combining red (460 nm) and blue colors (625 nm). The LEDs are arranged in parallel circuits to get a 12-volt input voltage with a composition of four red LEDs and one blue LED to get a red: blue ratio of 4:1 (Aji *et al.*, 2022). The LEDs circuit is arranged in the plant factory, as shown in Figure 4.

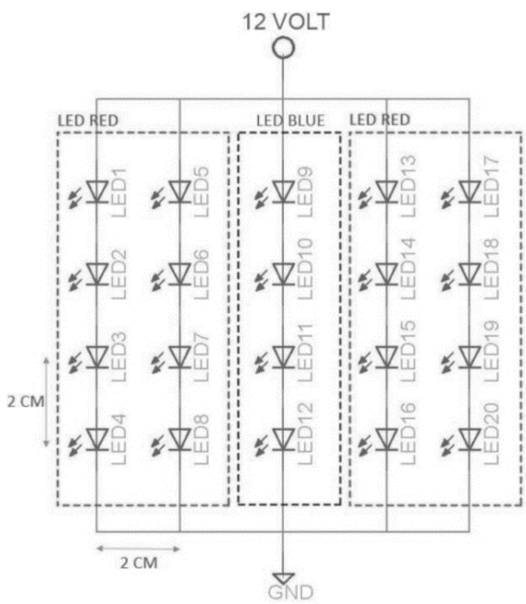

Figure 4. LED Light Circuit Design (Aji *et al.*, 2022)

2.3. Measuring Method

Plant growth measurement data were plant height and number of leaves measured every seven days. The plant yields measured were the fresh plant shoot weight 35 days after transplanting. Furthermore, plant quality is measured based on protein and vitamin C content. The leaf samples used were picked at harvest and mixed for quality measurement. Protein content was measured by Kjedahl method (Riikonen et al., 2016). Vitamin C was determined by titration method (Yan *et al.*, 2019).

2.4. Data Analysis

The data are tested for significance (α = 0.05) by SPSS20.0 software with one-way analysis of variance (Onaway- ANOVA) and multiple comparisons (LSD).

3. Result and Discussion

3.1. Plant height and number of leaves

Plant height and number of PakCoy leaves cultivated in the indoor hydroponic PFAL system were very different for each given irradiation time treatment. The length of irradiation significantly affects plant height and the number of leaves in each measurement week. Maximum irradiation for 24 hours supports the optimal growth of Pakcoy plant height and number of leaves.

Long irradiation with an intensity of 100 µmol/m^2/s for 24 hours gave the maximum height, i.e., 22.9 cm, followed by 20 hours/day of irradiation (21.3 cm), 16 hours/day of irradiation (17.6 cm), and 12 hours/day of irradiation (15.4 cm) (Shown in Figure 5). Table 1 shows that between the treatments 12 hours/day and 16 hours/day, and between 20 hours/day and 24 hours/day, there was no significant difference in plant height. There was a significant difference in plant height between the 16 hours/day treatment and the longer irradiation length (20 hours/day and 24 hours/day).

Table 1. Effect of different irradiation treatments on plant height, number of leaves, fresh plant shoot weight, protein, and vitamin c of Pakcoy

Length of irradiation (hours)	Plant height (cm)	Number of leaves	Fresh plant shoot weight (g/plant)	Protein (%)	Vitamin C (mg/100 g)
12	15.4 a	15.67 a	9.6 a	27.25 a	257.8 a
16	17.6 a	16.33 a	17.3 a	30.47 b	262.41 ab
20	21.3 b	18.33 b	31.5 b	28.01 ab	269.71 b
24	22.9 b	20.33 c	46.7 c	26.21 a	278.87 c

Note: Numbers in the same column followed by the same letter were not significantly different by DMRT 5% level

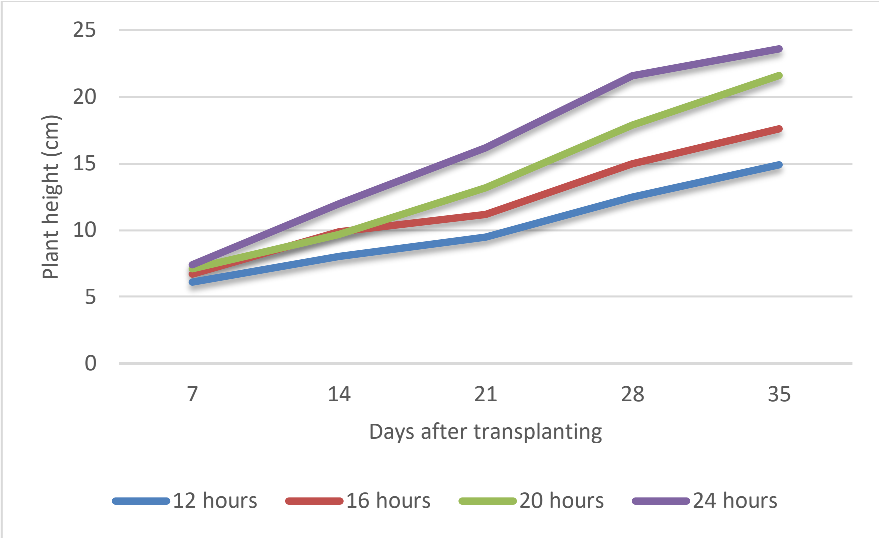

Figure 5. Pakcoy Plant Height (cm) in PFAL of Hydroponic Production Chamber

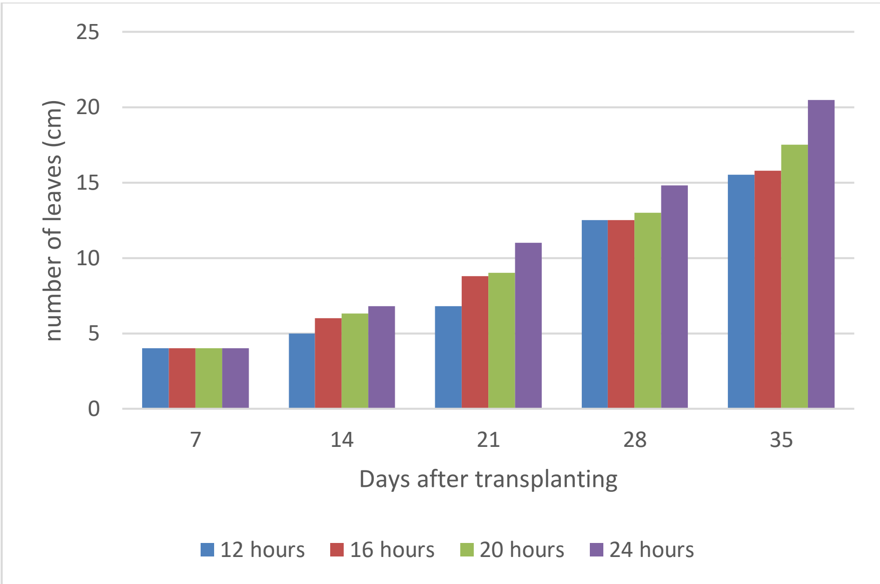

Figure 6. Number of leaves of Pakcoy Plant in PFAL of Hydroponic Production Chamber

As shown in Figure 5 and Figure 6, the highest number of leaves was also produced in the longest irradiation time of 24 hours/day, i.e., 20.33, followed by 20 hours/day of irradiation (18.33), 16 hours/day of irradiation (16.33), and 12 hours/day of irradiation (15.67) (Shown in Figure 6). Between the treatments of 12 hours/day and 16 hours/day, there was no significant difference in the number of leaves. Meanwhile, there were substantial differences in the number of leaves between 16 hours/day and 20 hours/day, between 16 hours/day and 24 hours/day, and between 20 hours/day and 24 hours/day.

Figures 5 and Figure 6 show that the heat level of 100 mol/m^2/s applied to pakcoy plants gave the maximum effect on plant growth when irradiation was given for 24 hours. This result is also in line with Kang *et al.* (2013) research which reports that providing a longer duration of irradiation results in better growth in lettuce plants due to a higher photosynthetic capacity (Kang *et al.,* 2013). In the treatment with a lower irradiation time, the lack of light inhibits the physiological processes of the plants by reducing the production of carbohydrates (Fairuzia *et al.*, 2022) which results in lower plant height and number of leaves of Pakcoy.

3.2. Shoot fresh weight

The highest fresh plant shoot weight was obtained at full irradiation for 24 hours (Table 1), i.e., 46.7 g/plant, followed by 20 hours/day of irradiation (31.5 g/plant), 16 hours/day of irradiation (17.3 g/plant), and 12 hours/day of irradiation (9.6 g/plant). Between the treatments, 12 hours/day and 16 hours/day, there was no significant difference in fresh plant shoot weight. Meanwhile, there were significant differences in fresh plant shoot weight between 16 hours/day and 20 hours/day, between 16 hours/day and 24 hours/day, and between 20 hours/day and 24 hours/day.

The increase in fresh plant shoot weight was in line with the increase in the duration of artificial light irradiation, which was supported by the plant height and the maximum number of leaves at the maximum irradiation time (24 hours). This condition is closely related to the amount of radiation given to the photosynthetic process of plants. The longer the irradiation is given, the greater the weight of the plants produced (Kang *et al*., 2013). The biomass production at the highest irradiation length has not shown the optimal point reached in the Pakcoy plant production process. Therefore, a strategy is needed to increase the intensity of artificial light required to increase crop production in a hydroponic PFAL system, such as setting the irradiation length and the light intensity (Mao *et al.*, 2019).

3.3. Protein

The highest protein content of plants was obtained at 16 hours/day of irradiation, i.e., 30.47 %, followed by 20 hours/day of irradiation (28.01 %), 12 hours/day of irradiation (27.25 %), and 24 hours/day of irradiation (26.21 %). The 16 hours/day treatment showed a significant difference in protein content compared to all other treatments (Table 1). At the shortest irradiation length, even with the same PPFD (100 µmol/m^2/s), there is a shortage of photosynthetic products, so the formation of amino acids, which are part of the protein, is not optimal. This result is in line with research (Viršilė *et al*., 2019) which stated that at a low irradiation period, there was an increase in free amino acids that were not combined to form protein compared to a moderate irradiation period in lettuce plants.

Based on Table 1, the optimum irradiation duration that produces the highest protein content is an irradiation time of 16 hours/day followed by a decrease in protein content along with the addition of irradiation time, namely 20 hours/day and 24 hours/day of irradiation. In the longer irradiation treatment, the protein content decreased, which is thought to be related to the nature of the protein, which is easily damaged when exposed to excess heat. This protein content is also related to the nitrogen content of plants (Utami & Kristiningsih, 2021) because nitrogen plays a role in protein building. This study indicates that the optimum irradiation time for obtaining the highest protein content in pakcoy plants is 16 hours/day. With optimal lighting, nutrient processing activities run optimally in line with photosynthetic activity (Gabriel & Shafri, 2022).

3.4. Vitamin C

The highest vitamin C was found in plants that received 24 hours/day of irradiation, i.e., 278.87 mg/100 g, followed by 20 hours/day of irradiation (269.71 mg/100 g), 16 hours/day of irradiation (262.41 mg/100 g), and 12 hours/day of irradiation (257.8 mg/100 g). There was a significant difference in vitamin C content between the shortest irradiation treatment and all other treatments. In the 16 hours/day treatments there was no significant difference in vitamin C content with the 20 hours/day treatment. In comparison, the 24 hours/day treatment resulted in a significant difference in vitamin C content with the 20 hours/day treatment. These results show that the longer the irradiation, the higher the vitamin C obtained.

This study shows that increasing the duration of irradiation can increase the content of vitamin C in controlled lighting conditions and plant growth environments, such as in plant factories. This study is presumably in longer irradiation; the light conditions and temperature around the plants are affected by the amount of light received by the plants (Egorova *et al*., 2021). This condition affects the amount of light received, thus increasing the rate of photosynthesis. The increase in photosynthesis rate causes an increase in vitamin C content (Meas *et al*., 2020). The results showed that longer irradiation to a certain extent for each type of plant increased the vitamin C content, which agreed with the results reported by (Yan *et al*., 2019).

4. Conclusions

In the production of Pakcoy plants in the indoor plant factory system, the length of artificial light irradiation has been shown to affect the growth, yield and nutrients produced. For maximum growth, yield, and vitamin C content, irradiation is required for 24 hours. Meanwhile, the required length of irradiation is 16 hours/day to get the maximum protein content.

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