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Evaluation of Growth and Quality in Latuca Sativa L. under Different Photoperiods

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Abstract

The growth and quality of Latuca Sativa L. (Lettuce Meraviglia d'inverno) in a closed-type plant factory system with various photoperiods under the same daylight integral (DLI) were evaluated in this study. Four groups with 12 samples each were grown hydroponically under LED light sources with DLI of 4 mol/m^2/d ± 9% at 18h/6h, 12h/12h, 11h/1h and 9h/3h light/dark periods. The light sources were generated by LEDs with the wavelengths of 660 nm (red) and 450 nm (blue) under the same light intensity. In the evaluation, any occurrence of tipburn, marginal necrosis and leaf yellowing was counted as unqualified leaf. Results showed that the group under the higher photosynthetic photon flux density (PPFD) showed the highest yield and the lowest percentage of unqualified leaves under the same DLI. Under rapid photoperiod of 9h/3h, the yield increased even the PPFD was low. Low PPFD with high light dark ratio resulted in the highest percentages of physiological disorder and the lowest fresh mass. It suggests that yield of lettuce may be further increased by combining rapid photoperiods and high PPFD for the same energy cost.

Keywords: LED; Photoperiod; Tipburn; Plant factory; Growth Profile; Latuca Sativa L

1 INTRODUCTION

As world population increases, the demand of safe and stable food supply has become a major concern in modern society. Unfortunately, agricultural food production is getting more difficult to be maintained due to climate changes and the reduction of usable farming lands for urban developments in different major food producing countries. In recent years, the development of closed-type climate-controlled plant factories using artificial lightings has been proposed to alleviate this concern. This idea so far has gained significant interest because plant-factory provides a clean and non-toxic environment that would not be affected by weather and increases food productivity with controlled operating conditions and multi-stack growth platforms. Environmental factors such as room temperature, relative humidity, water supply, nutrient delivery and lighting can be controlled and optimized to promote plant growth under indoor cultivation. Plants grew in this environment are free of pesticide and heavy metals. Risk of chemical contamination is reduced and food safety is guaranteed. With all these benefits, researchers have now looked into different issues that can further promote growth for this type of environment. In [1], the authors employed LEDs with the wavelengths of 660 nm (red) and 450 nm (blue) as the artificial light source to promote growth. It was found that lettuce growth could be speeded up with different combination of LEDs with different wavelengths. This method was further extended to investigate the peak net photosynthesis rate of young tomato under different light intensities [2]. Weight of Brassica Chinensis was shown to be able to increase by applying very high frequency LED pulse lighting in the plant growth cycle [3]. It was also shown that the yield of lettuce could be increased by reducing the photoperiods [4, 5]. All these investigations provide valuable information about indoor cultivation. However, plant physiological disorders such as tipburns are not widely reported in lettuce production under the environment controlled plant factory. In [6], it was reported that high nutrient concentration and/or high light intensity can produce more tipburns due to poor transpiration rate that results with calcium deficiency in high growth rates. Though these tipburns will not affect the nutrient content of lettuce, these defects can greatly affect the plant's appearance and shelf life, and hence reduce their marketability. In this paper, we will look specifically into the tipburns in Latuca Sativia L and their association with photoperiods. From the results, we derive the optimal light conditions for both quality and quantity improvements.

2 MATERIALS AND METHODS

The evaluation started with placing water–moistened Latuca Sativa L. (Lettuce Meraviglia d'inverno) seeds in plastic trays that were placed near windowsill under ambient light conditions at room temperature. When the roots of the seedlings were long enough, they were transferred to horticubes with one seedling per foam. The horticubes were then transplanted to the 4 separate cultivation beds. Each cultivation bed has 12 holes (60 cm × 80 cm) with 20 cm spacing to allow growth. Nutrient film techniques (NFT) [7] were adopted along with microcomputer controlled water pumps to provide a constant nutrient flow to different cultivation beds in this evaluation. The nutrient solution consists of calcium nitrate tetrahydrate, potassium nitrate, mono potassium phosphate, magnesium sulphate and other trace elements with tap water, and was added periodically to maintain the electrical conductivity (EC) value at 700 to 800 ppm, pH value at 6 to 6.5.

The lettuces were grown in a closed-type plant factory environment with constant temperature at 23 ℃, relative humidity of 60%, and CO_2 level of 450 ppm. Four groups, each with 12 lettuce samples, were raised under different light/dark periods of 12h/12h, 18h/6h, 11h/1h and 9h/3h with the same light intensity under red/blue LEDs, where h is defined as the hour of light and dark periods. The DLI for the four different groups (A to D) was 4 mol/m^2/d ± 9% (moles of photons emitted per square meter per day). Groups A and B were grown under 12 hrs photoperiod while C and D were grown under 24 hrs photoperiod. The plants were harvested after 20 days of cultivation for investigation. Different physical parameters such as fresh masses and leave numbers were recorded for comparisons.

2.1 Led Light Sources

A LED lighting panel (80 cm x 60 cm) that utilised 88 LEDs was designed to generate the required light for the photosynthesis of the lettuce in the experimental evaluation. Because of lower photosynthetic photon flux density (PPFD) generated by red LEDs than blue LEDs, the light panel uses 64 red LED (660 nm) and 24 blue LEDs (450 nm) to ensure the same light intensity ratio between the two types. The average PPFD was measured with a photosynthetically active radiation (PAR) meter (Apogee MQ-200) at a distance 15 cm below the LED panel. Table 1 shows the specific peak emission wavelength (λp) and electrical characteristics of LEDs that were employed in the experiment. Table 2 shows the photoperiods and respective PPFD of the four different groups under the same daily light integral (DLI).

TABLE 1 SPECIFICATIONS OF LEDS USED FOR THE LED PANEL

LED type	**Peak wavelength λ_p (nm)**	**Viewing angle**	**Forward voltage V_{Fs} (V)**	**Forward current I_{Fs} (mA)**	**Number of parallel connected LEDs**	**Number of series connected LEDs**	**Total Number of LEDs**
Blue	450	120	3.7	350	4	6	24
Red	660	120	2.6	350	8	8	64

TABLE 2 SPECIFICATIONS OF LIGHT TREATMENTS FOR THE EXPERIMENTS

	Groups			
	A	**B**	**C**	**D**
Photoperiod (light hours/dark hours)	11h/1h	9h/3h	18h/6h	12h/12h
PPFD ($\mu mol\ m^{-2}\ s^{-1}$)	47	58	64	100

2.2 Control System

The evaluation system used a two-tier cultivation chamber as shown in Fig. 1. The lettuces were divided into 4 groups in the evaluation sharing the same nutrient solution and growth environment. A single-chip MCU was used to control the light sources, nutrient solution circulation, air flow, and maintain temperature, humidity, CO_2 level and concentration of nutrient solution at a constant level. In addition, a webcam was installed to monitor the plant morphogenesis distantly and record the growth status.

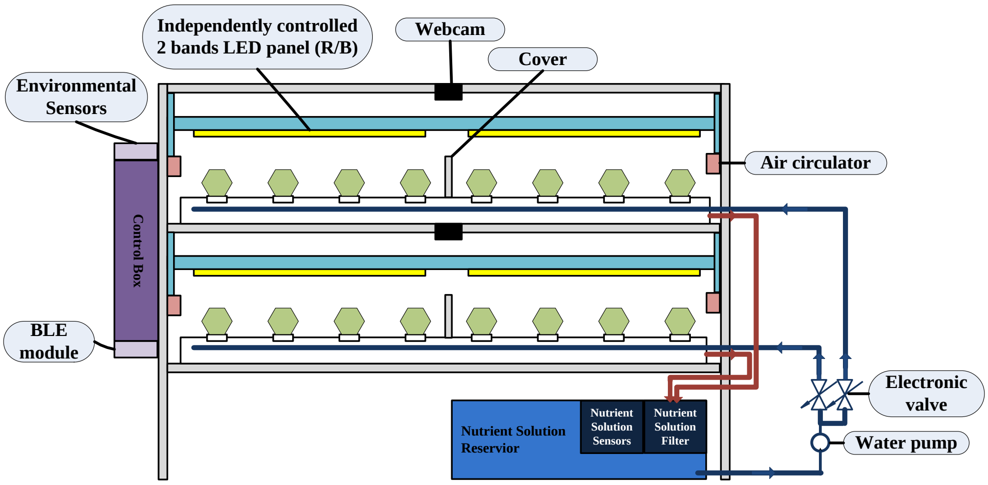

FIG. 1 EXPERIMENTAL SETUP

3 Experimental Results

Different physical measurements were conducted to evaluate the effect of photoperiod and light/dark period radio. Table 3 shows the number of leaves, fresh mass, dimensions of shoot and root that were recorded after 20 days of growth. Leaves that express a tipburn symptom were discarded and regarded as unqualified in the results.

TABLE 3 EXPERIMENTAL RESULTS UNDER DIFFERENT TREATMENTS

Experimental parameters	**Groups**			
	A (11h/1h) (47 μmol m^{-2} s^{-1})	**B (9h/3h) (58 μmol m^{-2} s^{-1})**	**C (18h/6h) (64 μmol m^{-2} s^{-1})**	**D (12h/12h) (100 μmol m^{-2} s^{-1})**
Total no. of leaves*	23.7 ±2.0	26.8 ±2.2	23.6 ±3.5	27.5 ±3.0
No. of Unqualified leaves* / (%)	9.5 ±2.1 (40.0%)	9.7 ±1.2 (35.9%)	8.1 ±1.9 (33.5%)	4.8 ±1.4 (17.8%)
No. of qualified leaves* / (%)	14.3 ±2.3 (60.0%)	17.3 ±1.7 (64.1%)	15.8 ±2.4 (66.5%)	22.6 ±3.0 (82.2%)
Total Fresh Mass (g)*	56.4 ±9.0	75.0 ±19.1	69.0 ±10.0	79.6 ±21.7
Shoot Mass (g)*	7.0 ±1.0 (12.7%)	7.4 ±1.9 (9.9%)	6.0 ±1.4 (8.5%)	5.7 ±2.1 (7.0%)
Unqualified Leaves (g)* / (%)	15.2 ±4.5 (27.0%)	14.4 ±5.37 (18.5%)	12.8 ±4.9 (19.1%)	4.4 ±1.7 (5.9%)
Qualified Leaves (g)* / (%)	34.8 ±8.1 (60.3%)	56.6 ±13.1 (71.6%)	50.8 ±9.2 (72.5%)	69.7 ±19.1 (87.1%)
Shoot Length (cm)*	11.0 ±1.7	6.5 ±1.6	5.2 ±0.7	4.8 ±1.2
Root Mass (g)	5.4	7.9	7.2	9.2

*Values are mean ±SD (n = 12)

3.1 Increased Photosynthetic Photon Flux Density under the Same Daily Light Integral

DLI measures the total number of photon having wavelength between 400 and 700 nm delivered during one day in a unit area. The light energy absorbed will trigger a series of photochemical reactions in photosynthesis converting the water and carbon dioxide into sugar for plant growth. On cloudy days, regular greenhouse will use LED as a supplemental lighting during darkness in order to increase DLI. In general, plants grown under the same DLI should receive the same amount of energy for photosynthesis and hence produce the same fresh mass. However, in our experiment, the fresh mass was different when the instantaneous photosynthetically active radiations were different even with the same DLI. The results in Fig. 2 showed a significant increase of fresh mass and number of qualified leaves when the PPFD was increased from 47 μmol m^{-2} s^{-1} to 100 μmol m^{-2} s^{-1} under the DLI of 4 mol m^{-2} d^{-1} ± 9%. The unqualified leaves under higher PPFD were also reduced significantly. It indicates that under the same DLI, plant growth will be enhanced on higher instantaneous photosynthetically active radiation rather than the total photon of light accumulated. It is also observed that, when the plant is grown under a higher PPFD, it will result in a lower percentage of physiological disorder. The occurrence of less tipburn, marginal necrosis and leaf yellowing increases the overall fresh mass and marketable rate of the produce.

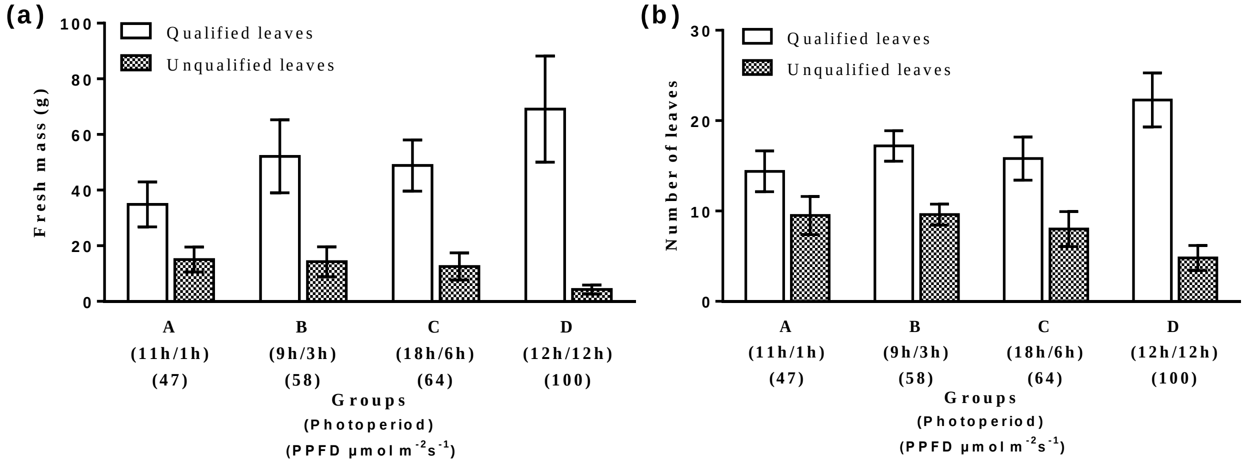

FIG. 2 THE LATUCA SATIVA L. SAMPLES GREW AFTER 20 DAYS WITH THE SAME DLI: (A) FRESH MASS, AND (B) NUMBER OF QUALIFIED AND UNQUALIFIED LEAVES.

3.2 Rapid Photoperiod under Low Light Condition

Also in Fig. 2, there is a sharp increase in fresh mass and number of qualified leaves in group B. The number of unqualified leaves is about the same in both Groups A and B. When the photoperiod was reduced from 24 hours to 12 hours, the shortened photoperiod results enhanced lettuce growth with increased fresh mass and reduced tipburn. The phenomena can be explained by the action of rapid removal of assimilates by translocation in the light-independent reaction of photosynthesis [4]. The inhibiting factors accumulated are removed during the dark period. From this evaluation, it shows that the photoperiod for plant growth can be optimized to produce better quality and increase yield for plant species.

4 CONCLUSIONS

In this evaluation, it shows that there is a significant trend in elevating the fresh mass and number of qualified leaves by increasing PPFD under the same DLI. When the photoperiod of lettuce is shortened to 12 hours, the fresh mass of qualified leaves is increased even under low intensity of photosynthetically active radiation. The shortened photoperiod compensates the inhibition of photosynthesis under low light condition. Our evaluation results suggest that the fresh mass of lettuce can be increased by adopting rapid photoperiods for same energy cost.

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