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Evaluating temperature variation of nutrient solution in Nutrient Film Technique (NFT) cooling system for temperate vegetable

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Abstract

The production of leafy green vegetables in hydroponic systems within greenhouses has gained global prominence in the fresh vegetable production industry. Hydroponic systems, particularly Nutrient Film Technique (NFT), are highly effective due to their soilless nature and efficient nutrient and water circulation. However, maintaining ideal greenhouse temperatures can be challenging. One strategy to reduce energy costs is to heat or cool the nutrient solution instead of the entire greenhouse environment. By regulating the root zone temperature through nutrient solution management, growers can provide more favourable conditions for temperate leafy greens. These conditions are critical because temperatures above 23°C can inhibit plant growth, while temperatures exceeding 35°C can significantly reduce plant metabolism efficiency. This study investigates how lettuce responds to nutrient solution cooling. Importantly, this research focuses on Malaysia, an equatorial country with a consistently warm and humid climate. In such environments, controlling nutrient solution or air temperature to match the crops' optimal growth requirements is crucial. The study employed Butterhead and Romaine lettuce varieties in a hydroponic NFT system. The EC (Environmental Cooling) treatment involved cooling the nutrient solution, while the RZC (Root Zone Cooling) treatment utilized environmental cooling. The results demonstrated that maintaining a consistent nutrient solution temperature within the range of 14°C to 18°C (as observed in the EC treatment) led to superior plant growth and quality, particularly in the early growth stages. In contrast, the RZC treatment showed temperature fluctuations, causing plant stress and inhibiting growth.

1. INTRODUCTION

Leafy green vegetable production in greenhouses using hydroponic system is becoming increasingly common globally and is playing a significant role in the global fresh vegetable production system (Khan, 2018). Due to its soilless nature and capacity to circulate nutrients and water, NFT hydroponic cultivation is very effective. For instance, hydroponic lettuce (*Lactuca sativa* L.) cultivation can yield ten times as much as conventional field agriculture, using 90% less water (Barbosa et al., 2015). Nevertheless, ensuring an optimal air temperature within a greenhouse can pose challenges, particularly in the midst of scorching solar heat, elevated external air temperatures, and heightened humidity levels during the hot season. Due to their high nutritional value for human health, leafy greens, which are young, tender, freshly harvested salad vegetables, are becoming increasingly popular with consumers (Saini, 2017). Even so, greenhouse hydroponic production can be energy-intensive due to the inherent cooling costs. It is important to look into practical ways to lower the energy cost for greenhouse production during challenging seasons.

To save money on energy, one strategy is to cool the nutrient solution rather than the entire greenhouse. By cooling the nutrient solution in the reservoirs, hydroponic systems make it simple to regulate the temperature in the root zone (Sakamoto and Suzuki, 2015). These narrower, cooler ranges can be strict, especially in the hot season when the high air temperature can stress the plants of these cool-season leafy vegetables. Air temperatures above 23°C can inhibit the growth of spinach plants, and air temperatures above 35°C can considerably reduce the efficiency of the plant's metabolism, causing bolting and lower yields (Lefsrud et al., 2005). For instance, root-zone cooling at 20°C increased the biomass of 'Wintergreen' lettuce grown aeroponically at air temperatures between 24°C and 38°C in a tropical greenhouse (Hooks et al., 2022). As opposed to solution temperatures of 20°C and 30°C, which induced stress responses in the entire plant, low nutrient solution temperature of 10°C led to reduced leaf and root growth in 'Red Wave' lettuce (Sakamoto and Suzuki, 2015). Although by controlling the temperature of specific greens, be it decreasing the temperature or increasing the temperature, the result of the crops may vary

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due to their characteristics. In Malaysia, the temperature is between 36°C - 40°C, which causes the crops to grow under constant room temperature. Hence, focusing mainly on cooling the nutrients or cooling the environment until the crops' optimal temperature for growth is reached is more relevant. This study was designed to demonstrate that producing temperate butterhead and romaine lettuce of higher quality can be accomplished by either controlling the temperature of the nutrient solution in NFT production systems or the temperature of the entire air space around the crops

2. MATERIALS AND METHODS

Butterhead lettuce (*Lactica sativa var*. capitata) and Romaine lettuce (*Lactuca sativa* var. longifolia) are the two types of plants utilized in this study. The ideal temperature range for Romaine is 15 to 18 °C, whereas the ideal range for Butterhead is 12 to 18 °C. Ten days after germination, plants were transplanted into the NFT vertical rack. The NFT structure of 140 cm in height, 60 cm in breadth, and 130 cm in length has 2 levels, separate light switches for each level and can accommodate up to 32 plants. The NFT vertical rack can hold 16 samples per layer, 32 samples will be used in total between the two racks.

This experiment was carried out at the Faculty of Agriculture, Universiti Putra Malaysia, Serdang, Selangor, in a greenhouse and fully air-conditioned cabin. Plants in the greenhouse utilize the impact of root zone cooling by water chiller, while plants in the cabin are affected by environmental cooling. The temperature sensors that have been employed utilise a resistance-based sensor to monitor the soil, air, or water temperature. This research makes use of about 6 units. The sensors are used to gather information on the temperature of the nutrients inside the NFT rack.

The Microstation Watchdog 1400 data logger was used to record temperature data. The Hailea HC chiller was for cooling the NFT nutrient water in the greenhouse. The plants were supplied with a nutrient solution of commercial A-B fertigation fertilizer (D Syira Enterprise, Seri Kembangan, Malaysia) with an electrical conductivity of 1.4 to 1.5 mS/cm. Two different treatments were employed in this study, treatment 1: NFT system with root zone cooling while treatment 2 NFT system with environment cooling.

Nutrient solution temperature in both treatments were measured at 1-minute interval. All data was logged and recorded in the Watchdog 1400 data logger. Plant growth parameters were measured each week for plant height and leaf width. The effects of each treatment on growth parameters were statistically analysed by t-test using Excel 2010 (Microsoft Corp, Redmond, WA, USA). Differences were considered significant when the p value was < 0.05.

3. RESULTS AND DISCUSSION

Based on Figure 1, the EC solution temperature remains constant compared to the RZC solution temperature. The consistent temperature in EC solution temperature leads to a relatively higher growth index of plants and better quality of plants (Table 1), especially during the early stage of growth. The temperature of the solution in EC is very compatible for the temperate vegetables to grow, which is between 14°C to 18°C thus resulting in better plant quality under EC conditions. Conversely, the RZC solution exhibited temperature fluctuations, with occasional increases and decreases in temperature. This causes the plants to become unable to adapt and maintain passive growth due to the temperature of the solution. As stated by Hatfield and Prueger (2015), plant productivity will be impacted by the predicted warming of the environment and the potential for more extreme temperature events.

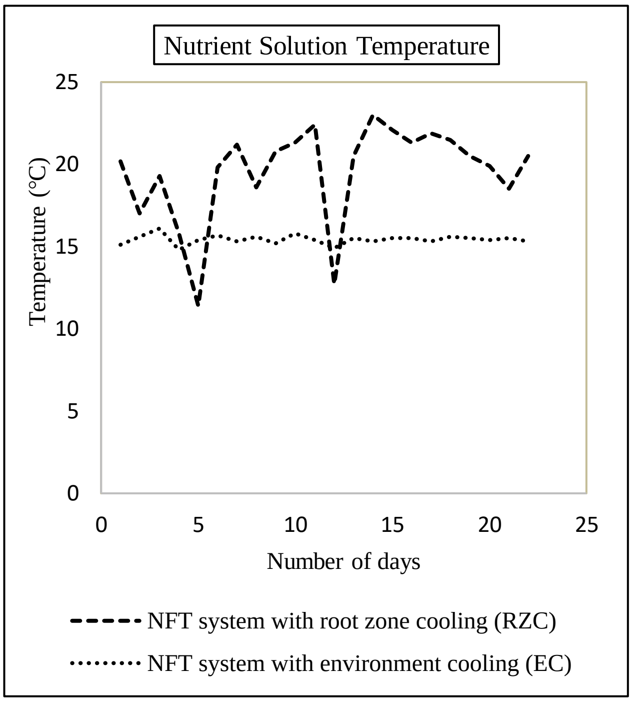

Figure 1. Mean daily profile of the nutrient solution temperature in NFT system with root zone cooling and environment cooling treatments

Inconsistent temperature patterns in the solution can be attributed to fluctuations in energy loss and variations in the surrounding temperature. When the vicinity around the rain shelter experiences high temperatures, the solution temperature exceeds the pre-set optimal level for plant growth. Conversely, when the ambient temperature drops, the solution temperature becomes too cold for effective nutrient absorption by the plants, leading to inhibited growth. Cultivating temperate vegetables in lowland areas necessitates meticulous monitoring and control of numerous parameters due to the unfamiliar environmental conditions for these crops.

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Table 1. Plant height and leaf width of butterhead and romaine lettuce with EC and RZC, at the early stage of growth (12 days after transplanting), values are mean ± standard error (n=16).

Days after transplant	Plants	Treatment	Plant height (cm)	Leaf width (cm)
12	Butterhead lettuce	EC	4.06 (±0.52)	2.74(±0.24)
		RZC	1.52(±0.2)	1.14(±0.07)
		t-value	4.39*	6.15*
12	Romaine lettuce	EC	4.32(±0.19)	2.15(±0.06)
		RZC	1.41(±0.29)	0.37(±0.06)
		t-value	8.11*	19.49*

*values are significant at $p< 0.05$, respectively.

As Olabomi et al. (2022) state, the soil temperature needs to be as low to grow these crops in the tropics as in a temperate area. Thus, this illustrates that the ability to maintain the pre-set temperature value for the solution significantly impacts the growth of temperate vegetables.

Table 1 presents data on the vegetative growth stage of Butterhead and Romaine lettuce under both EC and RZC conditions during temperature data collection. Plant height and leaf width for both butterhead and romaine lettuce were significantly had higher plant height and leaf width in EC compared to RZC treatment. For naturally temperate vegetables like Butterhead and Romaine lettuce, they are more compatible to be grown in an environment that is naturally or constantly under cool environments that have temperatures between 15°C to 18°C. Rezazadeh (2018) noted that plants attained their maximum height at 25°C, as this temperature was most conducive to their growth. Conversely, at 35°C, there was a significant reduction in plant height; at 15°C, the plants exhibited the shortest growth. These temperatures have been shown to optimize the growth of both crops to their ideal levels. Maintaining the right temperature to nurture crops will improve crop development.

4. CONCLUSION

In conclusion, this study has highlighted the pivotal role of temperature control in influencing the growth and quality of temperate vegetables, as evident from Figure 1 and Table 1. The EC solution's ability to maintain a consistent temperature range, particularly between 14°C and 18°C, has resulted in superior plant growth and improved plant quality, especially in the early stages of development. This underscores the compatibility of these temperatures with the needs of temperate vegetables.

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