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(Research Article)

Cooling the high temperature nutrition solution to improve growth, yield and water productivity of hydroponic red lettuce (*Lactuca sativa* L Var Red rapids) in a tropical location

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Abstract

Red lettuce is preferred because of its high nutritional, vitamin, and antioxidant contents. Hydroponic cultivation has been known to successfully improve the quality and productivity of red lettuce. But the efforts to increase the productivity of hydroponic red lettuce face constraints of high temperatures in the tropics. The aim of this study was to compare the growth, yield, and water productivity of red lettuce in three hydroponic systems namely wick, floating raft, and dry systems by controlling the temperature of the nutrient solutions using protected nutrient containers. The experimental design of randomized complete block split plots with the main plots of the nutrient containers which consisted of three levels: Refrigerated container, styrofoam-insulated container, and bare bucket container in which the nutrient solution was delivered to plants in three separated gutters as the cultivation beds, then recirculated back to the corresponding nutrient container. The secondary plot is hydroponic systems including three systems namely wick, floating raft, and dry systems. The blocks were the arrangement of plants according to the flow direction of the nutrient solution, namely upstream, middle and downstream in each gutter. Each experimental unit was represented by 3 plants. Data sets were analyzed by using analysis of variance and followed by LSD multiple comparisons at the 5% level. The results showed that the temperature of the nutrient solution controlled by the three containers had a significant effect on all observed plant parameters. Meanwhile, the hydroponic systems and the blocks had no significant effect. The use of Refrigerated container showed the best performance in improving the growth, yield, and water productivity of the red lettuce.

Keywords: Nutrient solution temperature; Wick; Floating raft; Dry system; Red lettuce

1. Introduction

Lettuce (*Lactuca sativa* L.), one of the most popular leafy vegetables, is cultivated all over the world. Its economic role is important as indicated by its production and trade value. Based on FAO's statistic, the global production of lettuce is consistently increasing from 24.66M tons in 2010, to 27,66M tons in 2020, where China is on the top producer making up more than 50% of the production. The world's export value reached USD 1.86B in 2021, where Spain is the number one exporter [1].

Consumed in fresh as salad mixes and as topping of sandwich, lettuce is known as nutritious leafy vegetable, for example it contains 4.25 mg/g - 9.65 mg/g of soluble protein, 15.5-33.2 mg/100g of vitamin C, free amino acid 100.25 – 750 µg/g [2] and minerals. For red pigmented leaf lettuce, the content of antioxidant substances is exceptional. Kim et al. [3] reveal that green-red leaf lettuces contain total carotenoids of 60.8-108.0 µg/g FW, total folate of 7.74-9.39 µg/g DW, Cyanidin of 87.9-563.5 µg/g DW, and TPC of 8.6-45.6 mg of GAE eq/g DW for oak-leaf cultivars. Depending on the

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intensity of red color and leaf shape; dark red, circular leaf shapes, and strong undulated leaf are even richer in antioxidants content [4] .

High temperature is the primary challenge for growing lettuce in tropical regions like in Indonesia since lettuce is a cool-weather lover that has optimum range of 4 to 27°C. Extreme temperature will lead to be poor growth, bolting/elongating, lower yield, and bitter taste [5]. This is why the yield of lettuce in tropical regions has never been as good as the production in subtropical countries, as shown by the statistic that the most major producers are located in subtropics [6]. At low terrain, Indonesian farmers normally cultivate lettuce on open farm at rainy season in order to get some reduction of the adverse effect of the high temperature.

Lettuces of various cultivars have not been among the 25 major vegetable crops grown in Indonesia [7] but they are produced rather as premium vegetables. Some groups of Indonesian farmers have been hydroponically growing lettuces in plastic-roofed greenhouses with varied levels of technology and investment. Although the data has not been well established, the growing farming system in some urban vicinity is noticeable. Except at high land, extreme temperature in the greenhoses is unavoidable because controlling the greenhouse temperature is not likely to be feasible for common farmers in Indonesia. Daily temperature in Indonesia is around 30-37°C or even higher in dry season. Some heat tolerant cultivars like green and green-red oak leaves are common among the growers, in order to tolerate high temperature.

Maintaining the nutrient solution cool to acceptable limit seems to be a more promising alternative rather than controlling the greenhouse's air temperature [8]. High temperature of the nutrient solution could promote the element settling, alter pH and EC, lower dissolved oxygen level, and eventually hinder nutrient absorption [9], [10]. Controlling the nutrient solution temperature has been demonstrated to improve growth and yield of some hydroponic vegetables such as cucumber [11], tomato [12], mustard [13], lettuce [14], and some positive effects are reported. Some insulation materials such as Styrofoam are normally used to protect the nutrient solution containers from direct sun light thus low temperature can be maintained. More proven technique to cool the nutrient solution of hydroponic cultivation is by implementing mechanical cooler machines, such as refrigerators or chillers. The energy balance of using cooler machine to control nutrient temperature has been investigated by. Cortella et al. [15], The use of such technique has also shown better yield of brassicas hydroponically cultivated [13], although the economic feasibility has not been reported.

This research was intended to observe the effectivity of using three different methods in controlling the nutrient solution temperature to improve the growth, yield, and water productivity of red rapid lettuce. The use of red rapid lettuce because this cultivar has the potential to be promoted as a premium vegetable for it is known as rich in antioxidants (health promoting substances), in addition to its heat tolerance characteristics and aesthetically pleasing as an ornamental vegetable.

2. Material and methods

2.1. Description and set up

This research was carried out from February to May 2021 at the Department of Agricultural Engineering, Faculty of Agriculture, University of Lampung located at 105°24'24.509" E longitude, 4°33'30.906" S latitude, and 121 m elevation. Average high temperature ranges from 30°C in January to 32°C in October, humidity from 78% in September to 84% in February to May, rainfall from 89 mm in July to 278 mm in January. Materials used in this research consisted of the red lettuce seed and AB mix nutrient purchased from nearest farm shops.

Hydroponic cultivation of the red rapid lettuce was setup on 1 m raised bed in a mini greenhouse roofed with 14% UV plastic and enclosed with 30 mesh insect net. The greenhouse air temperature was recorded as in Figure 1, the averages of which were 24±0.96 °C at 07:00, 32±2.4 °C at 13:00, and 28±1.7 °C at 17:00.

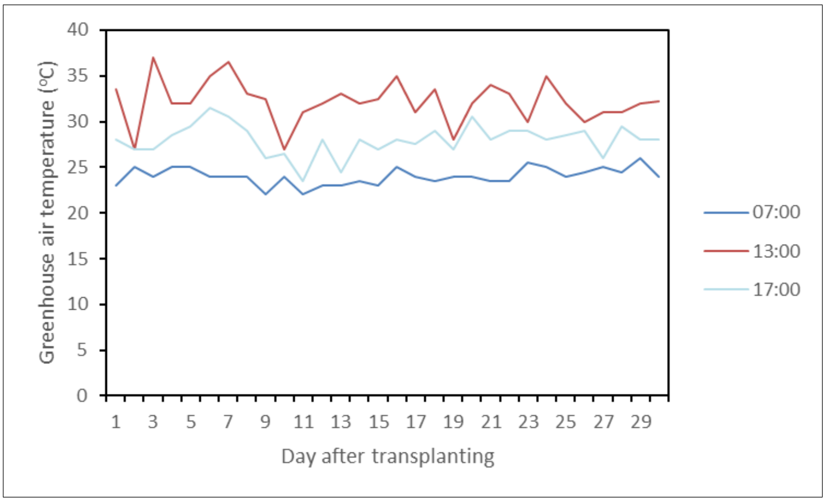

Figure 1 Greenhouse air temperature at 07:00, 13:00, and 17:00

The nutrient solutions were stored and controlled in three different containers namely electrical-mechanical or refrigerated cooler, Styrofoam insulated bucket, and bare bucket for three different beds. Each bed consisted of a serial double gutter making it total of 8 m long (Figure 2). The nutrient solution was continuously circulated by using small pumps to the first row of crops, flowing to the second row (about 10 cm depth), and returned back to the containers. The temperature of nutrient solution was possibly increasing along the gutter bed, and cooled back in the containers with some different degree of cooling rates.

A long the gutter bed there were three different hydroponic systems namely: wick, floating raft, and dry system. The wick system is characterized by the existence of an air gap between water surface and fix plant medium support. A piece of fabric wick is used to deliver the nutrient solution to the plant roots by capillary force. Advantage of the wick system is that the plant root get balance oxygen and nutrient from the air gap and the nutrient solution as well. The air gap also helps of cooling down the temperature in the root zone.

The other system is floating raft which is characterized by free floating plant medium support on the nutrient solution surface. This system is simple in maintenance but the plant is known to becomes susceptible to the fluctuating nutrient temperature. The last, dry system is basically the same as the floating raft in the initial growth phase of plant. When the root is still short enough, plant get nutrient from the medium (normally rockwool) because the rockwool medium is still allowed to be submerged under the nutrient surface. But when the root is already long enough, the nutrient solution surface is lowered down so an air gap between the nutrient surface and the plant medium is created. By doing this mechanism the plant growth medium looks dry and clean while the root still obtains the nutrient because lower parts of the root is still submerging under the nutrient surface.

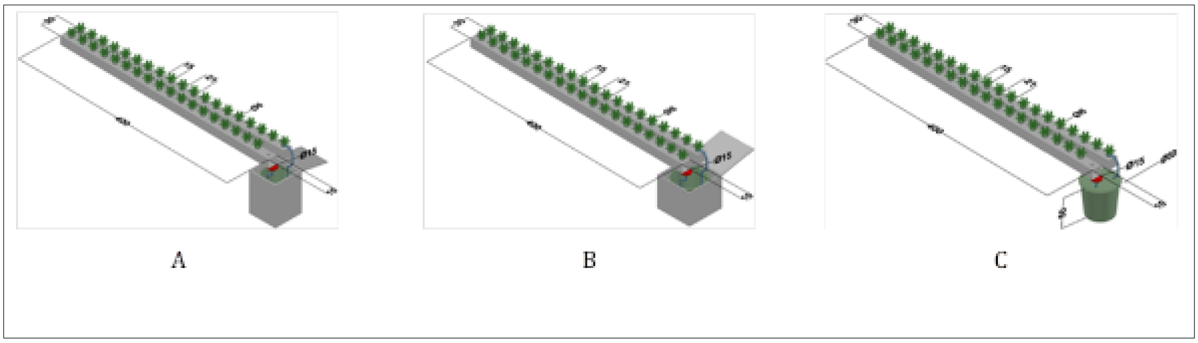

Figure 2 Hydroponic setup with three different beds with 3 different nutrient solution containers: a. refrigerated cooler, b. Styrofoam-insulated bucket, c. bare bucket

2.2. Seedling preparation

The research was initiated by seedling the plant seed on the rockwool medium. First the rockwool slab was cut into small pieces of 3x3x3cm cubes and placed on the seedling tray. After soaked in water for about 1 hour, one good seed was inserted into each of the top side of the rockwool cubes. Then the prepared seedling in the rockwool was wetted with enough water, covered with paper, and place into the dark. The seedling was monitored thereafter, the paper cover was opened, and moved to shaded place after germination sign was emerging. Seedling was selected and transplanted to the hydroponic beds after about 21 das (days after seedling). Mild electrical conductivity (EC) of nutrient solution was given in initial phase of plant growth, then increased gradually for the following phases of growths.

2.3. Experimental Design

The experimental design used was a randomized complete block design (RCBD), with the treatments distributed in split-plot. The nutrient solution container namely: Refrigerated container (R), Styrofoam insulated container (S), and bare bucket container (B) were used as the whole plots. While the hydroponic systems namely: wick (W), floating raft (F), and dry system (D) were used as the split/sub plots. Three plants per experimental unit were positioned into three blocks along the gutter bed namely upper, middle, and down streams. The blocking was used to anticipate the significant effect of increasing nutrient solution temperature along the gutter.

2.4. Observation and Measurement

The parameters of the nutrient solution monitored included pH, EC, temperature (using electrochemical methods). The plant growth parameters measured consisted of plant height (using rules), number of leaves (count), stalk diameter (using caliper). The plant yield parameter measured consisted of canopy area (using gravimetry and top view photograph of a standard and the plant canopy areas), fresh weight (gravimetry), dry weight (gravimetry), ash content (gravimetry). Water consumption (daily different level of the nutrient stock in the containers) and water productivity (yield divided by the water consumption).

2.5. Data Analysis

Data set obtained from the parameter measurements was analyzed by using analysis of variance (ANOVA) at 5% level. The significant differences among means were further tested by using LSD multiple comparison.

3. Results and discussion

3.1. Nutrient Solution Temperature

Electrical Conductivity (EC) of the nutrient solution was given according to the growth phase of the plant. Mild EC of 1.4 mS/cm was given at the first week, then elevated gradually to 1.7 mS/cm at a week before the harvest time. Acidity of nutrient solution or pH was recorded as not much different among the three gutters, ranging from 6.5 to 6,8. The temperatures of the nutrient solution at the inflow and outflow ends were recorded three times a day at 07:00, 13:00 and 17:00 (Table 1). The temperatures were all increasing from morning to noon, and decreasing in the afternoon. Changes of the temperature from the inflow end to the outflow end were not much, just around ±1°C, but the temperature differences among the three gutters with different the nutrient solution containers were very significant particularly between morning temperature and noon temperature. In the morning, the temperatures of the nutrient solution were all about tolerable for the normal plant growth, ranging from 20.70±0.75 to 25.80±0.58°C. At noon, the temperatures of the nutrient solution were very high ranging from 26.93±1.35 to 32.20±1.23 °C for all the three treated containers. Then the temperatures were all decreasing in the afternoon, ranging from 25.50±1.35 to 30.60±1.19.

Among the three types of the nutrient containers, the data showed that the refrigerated container was the best in maintaining the nutrient solution temperature, which was ranging from 20.70±0.75°C in the morning to the highest of 27.45±1,27°C at noon. While the Styrofoam insulated container was not so successful, not so different from the bare bucket container, in term of maintaining the nutrient temperature stability because the temperature was still increasing to the highest of 31.20±1.07°C at noon. Temperature as high as 27°C is out of the tolerable ranges for normal plant growth [5].

Table 1 Temperatures of nutrient solution in the gutters recorded at 07:00, 13:00, 17:00

Nutrient Solution Container	**Temperatures (°C)**	
	Inflow End	**Outflow End**
Morning (07:00):		
Refrigerated	20.70±0.75	21.40±0.74
Styrofoam-Insulated	25.55±0.52	25.50±0.57
Bare bucket	25.80±0.60	25.80±0.58
Noon (13:00):		
Refrigerated	26.93±1.35	27.45±1,27
Styrofoam-Insulated	31.10±1.08	31.20±1.07
Bare bucket	32.20±1.23	32.10±1.24
After Noon (17:00):		
Refrigerated	25.50±1.35	26.00±1.30
Styrofoam-Insulated	30.10±1.07	29.90±1.06
Bare bucket	30.60±1.19	30.30±1.08

3.2. Plant Growth

The influence of the hydroponic system namely wick (W), floating raft (F), and dry system (D) were not significantly different. The blocks namely upper, middle, and down streams of the gutters were not significantly either. Therefore, the discussion is focused on the whole plot (the container system of the nutrient solution), namely refrigerated container, Styrofoam insulated container, and the bare bucket.

Data recorded from transplanting time to harvest showed that plant height from the bed with refrigerated nutrient container was consistently taller than plants from the beds with Styrofoam insulated container and those with the bare bucket (Figure 2a). At harvest time, statistical analysis showed that the plant height in the bed with the refrigerated nutrient container reached 19.8 cm, significantly taller than the plant height in the other two beds. Whereas, plant height in the bed with Styrofoam insulated containers (16.7 cm) and plant height in bed with bare bucket containers (15.7 cm) were not significantly different. This was one indication of the effect of the nutrient solution temperature on the plant growth, and the refrigerated container was the most effective to improve the plant growth, while the Styrofoam insulated container was not so effective.

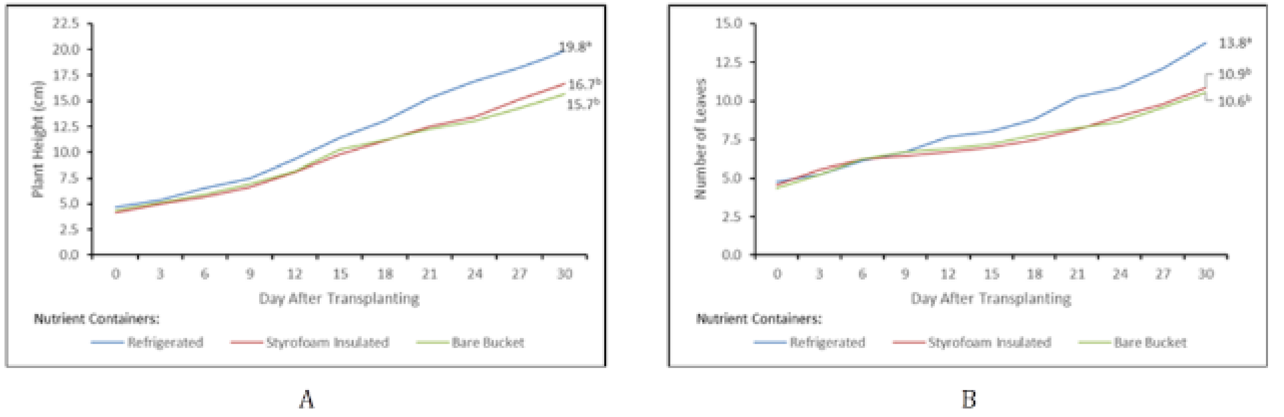

Figure 2 a) Plant height, b) number of leaves (means with the same letter were not significantly different at 5% level)

The parameter of the number of leaves showed a similar indication as the plant height, consistently higher than those from the Styrofoam and bare bucket containers at the most time. At the harvest time, the number of plant leaves from the bed with refrigerated container (13.8) was significantly higher at 5% level than those either from the bed with the Styrofoam insulated nutrient container (10.9) nor from the bed with the bare bucket (9.6) (Figure 2b), while the number of plant leaves from the beds with the Styrofoam container and those from the bed with the bare bucket were not significantly different. The highest number of leaves (13.8) was a confirmation that the temperature of nutrient solution strongly affected the plant growth, and the refrigerated container of the nutrient solution was the most effective in cooling the nutrient temperature, while the Styrofoam insulated container and the bare bucket was not.

3.3. Plant Yield

The plant yield parameters were recorded at the harvest time, not over time of the plant growth. All the parameters showed that the treatment of the refrigerated nutrient container gave consistently the best performance (Table 2). Plants from the bed with the refrigerated nutrient container had the best yield in terms of the Canopy area and the root length by 633.00 cm^2/plant and 32.99 cm/plant respectively. Kawasaki et al. [16] stated cooling the root zone could promote the root growth and nutrient uptake. They found that cooling the root zone by 24.7^{o}C even in the high air temperature (30.8 and 33.7°C) could produce the best growth and yield. Sun et al. [17] explained that root zone cooling improved plant photosynthesis by increasing stoma conductance, enhancing CO_2 supply, promoting photosynthetic electron transport, and stimulating phosphorylation, which in turn improved photochemical efficiency.

For the marketable parameter, the fresh weight, the treatment of the refrigerated nutrient container produced the best yield by 103,50 g/plant, meaning that the treatment was the most profitable economically rather than the other two treatments, regardless the electrical energy consumed. Cortella et al. [15]. showed if electrical power was managed properly, the application of the powered cooling and heating of the root zone would be financial gain. The best yield of 103.5 g/plant at 30 DAT, anyway, was better than the fresh Grand Rapids of 87.23 g at the same DAT grown on the soil as reported by Hasan et al. [18] Other finding reported by He et al. [19] also showed that cooling the root zone by 20^{o}C could produce the highest fresh biomass of lettuce cultivated aeroponically in the tropics.

Dry weight of the plant biomass (5.68 g/plant) was also the highest, about the same as Thompson [20] found when they treated the root zone temperature by 24^{o}C, in a semitropical location. The best result was also reported by Masaru et al. [21] when they are applying 10^{o}C and 20^{o}C for root zone of strawberry. Best growth and yield were also observed by Lee et al. [8] when they cultivated ophiorrhiza pumila at the root-zone temperature of 20^{o}C.

In term of percentage, however, the dry matter was 5.6%, the lowest as compared to the plant with the styrofoam insulated container (8.1%) and to the plant with the bare bucket container (7.7%). In other words, there was slightly more water content in the plant grown with the refrigerated nutrient container (94.4%) as compared to that of Styrofoam insulated container (91.9%) and to that of the bare bucket (92.3%).

Regardless of the lowest dry matter percentage, the refrigerated container treatment gave the highest ash content. The ash content of the plant with the refrigerated container was 23.19% while those from the styrofoam and the bare bucket were 15.75% and 14.35 respectively. This fact indicated that cooling the nutrient temperature with the refrigerated nutrient container could produce better quality of the red lettuce.

Table 2 Plant Yield

Plant Parameters	**Types of Nutrient Container**		
	Refrigerated	**Styrofoam Insulated**	**Bare Bucket**
Canopy Area (cm^2/plant)	633.00^a	437.90^{ab}	265.20^b
Root Length (cm/plant)	32.99^a	28.58^b	22.61^b
Fresh Weight (g/plant)	103.50^a	37.28^b	32.74^b
Dry Weight (g/plant)	5.68^a	2.82^b	2.53^b
Ash Content (%)	23.19^a	15.75^b	14.35^b

*) means with the same letter were not significantly different at 5%

3.3.1. Water Productivity

Another parameter of nutrient solution that is important to monitor is the evapotranspiration from the three gutters which is measured daily (Figure 3a). The data showed that from the beginning of transplanting to harvesting, the evapotranspiration of nutrient from the refrigerated container (6.63 L/plant) was always higher than the evapotranspiration of nutrients from the Styrofoam insulated container (4.44 L/plant) and the bare bucket (3.85 L/plant). Meanwhile, evapotranspiration from the styrofoam insulated container and from the bare bucket was not so different. The rate of evapotranspiration is affected by plant health, temperature, and nutrient concentration. The high evapotranspiration of nutrient from the refrigerated container indicated that the health of the plants in this bed was better than those in the Styrofoam insulated container or the bare bucket. The low evapotranspiration of the nutrients from the Styrofoam insulated container and from the bare bucket were strong indications that the plants in the other two beds were suffering from the heat stress.

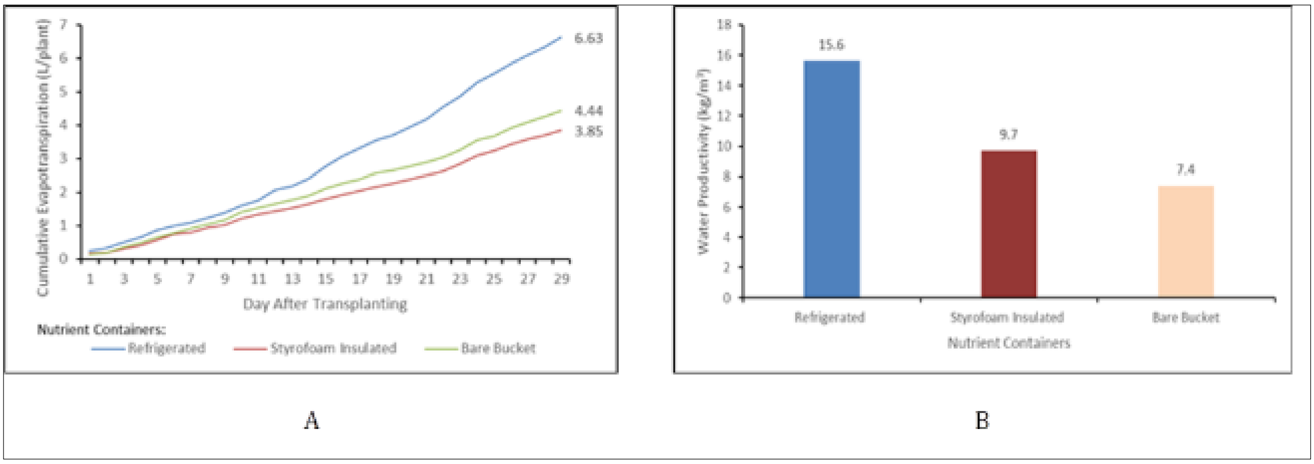

Figure 3 a) Cumulative evapotranspiration, b) Water productivity

The term of water productivity is generally also called as the water use efficiency (WUE). Figure 3b shows that the treatment of the refrigerated nutrient container gave the highest water productivity (15.6 kg/m^3) than the water productivity given by the Styrofoam insulated container (9.7 kg/m^3) and given by the bare bucket container (7.4 kg/m^3). In other words, cooling the nutrient solution by using the refrigerated container resulted in the most productive water in the hydroponic cultivation of red lettuce in tropical regions. The best water productivity of 15.6 kg/m^3) was slightly better than the red lettuce grown organically on the previous research study [13].

4. Conclusion

The Adverse effect of high atmospheric temperature of tropical regions on the red lettuce cultivation could be resolved by modifying the nutrient solution temperature. The refrigerated nutrient container was found to be superior in maintaining the nutrient temperature low and significantly improve both the growth and the yield of the red lettuce, as compared to the Styrofoam insulated or bare bucket containers. The hydroponic types namely wick, floating raft, and dry systems could equally produce 15.6 kg lettuce per m^3 nutrient solution when the refrigerated nutrient container was incorporated in the hydroponic system.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflict of interest.

Author's contributions

All the authors in the team are getting involved in this research work. Andini Prima Rosa contributed much in operational running of this research, Oktafri Rahman and Ahmad Tusi were responsible for plant water relationship and hydroponic system, Mareli Telaumbanua set refrigeration usage, Agus Haryanto and Sugeng Triyono handled the experimental design and the hydroponic setup.

References

[1] Tridge, "Fresh Lettuce." Accessed: Jun. 30, 2024. [Online]. Available: https://www.tridge.com/intelligences/lettuce/production

[2] J. Song et al., "Nutritional quality, mineral and antioxidant content in lettuce affected by interaction of light intensity and nutrient solution concentration," Sci Rep, vol. 10, no. 1, Dec. 2020, doi: 10.1038/s41598-020-59574-3.

[3] D. E. Kim, X. Shang, A. D. Assefa, Y. S. Keum, and R. K. Saini, "Metabolite profiling of green, green/red, and red lettuce cultivars: Variation in health beneficial compounds and antioxidant potential," Food Research International, vol. 105, pp. 361–370, Mar. 2018, doi: 10.1016/j.foodres.2017.11.028.

[4] A. D. Assefa, O. S. Hur, B. S. Hahn, B. Kim, N. Y. Ro, and J. H. Rhee, "Nutritional metabolites of red pigmented lettuce (Lactuca sativa) germplasm and correlations with selected phenotypic characters," Foods, vol. 10, no. 10, Oct. 2021, doi: 10.3390/foods10102504.

[5] M. Khan, "Effect of high temperature and exposure duration on stem elongation of iceberg lettuce," Article in Pakistan Journal of Agricultural Research, 2018, doi: 10.21162/PAKJAS/18.655.

[6] M. V. Shatilov, A. F. Razin, and M. I. Ivanova, "Analysis of the world lettuce market," in IOP Conference Series: Earth and Environmental Science, Institute of Physics Publishing, Nov. 2019. doi: 10.1088/1755-1315/395/1/012053.

[7] Badan Pusat Statistik, "Produksi Tanaman Sayuran Menurut Provinsi dan Jenis Tanaman, 2021." Accessed: Jun. 30, 2024. [Online]. Available: https://www.bps.go.id/id/statistics-table/3/ZUhFd1JtZzJWVVpqWTJsV05XTllhVmhRSzFoNFFUMDkjMw==/produksi-tanaman-sayuran-menurut-provinsi-dan-jenis-tanaman--2021.html?year=2021

[8] J. Y. Lee, M. Hiyama, S. Hikosaka, and E. Goto, "Effects of concentration and temperature of nutrient solution on growth and camptothecin accumulation of ophiorrhiza pumila," Plants, vol. 9, no. 6, pp. 1–14, Jun. 2020, doi: 10.3390/plants9060793.

[9] F. Gourds Shoji TACHIBANA, "Effect of Root Temperature on the Rate of Water and Nutrient Absorption in Cucumber," 1987.

[10] L. I. Trejo-Téllez and F. C. Gómez-Merino, "Nutrient Solutions for Hydroponic Systems," in Hydroponics - A Standard Methodology for Plant Biological Researches, InTech, 2012. doi: 10.5772/37578.

[11] M. S. Al-Rawahy, S. A. Al-Rawahy, Y. A. Al-Mulla, and S. K. Nadaf, "Effect of Cooling Root-Zone Temperature on Growth, Yield and Nutrient Uptake in Cucumber Grown in Hydroponic System During Summer Season in Cooled Greenhouse," Journal of Agricultural Science, vol. 11, no. 1, p. 47, Dec. 2018, doi: 10.5539/jas.v11n1p47.

[12] M. Anza, P. Riga, B. I. Epalza Arana, S. Arazuri, C. Jaren, and N. Arias NEIKER, "Effect of Root-Zone Heating on the Yield and Some Quality Parameters of Hydroponically Grown Tomato."

[13] S. Triyono, R. M. Putra, S. Waluyo, and M. Amin, "The effect of three different containers of nutrient solution on the growth of vegetables cultured in DFT hydroponics," in IOP Conference Series: Earth and Environmental Science, Institute of Physics Publishing, Nov. 2019. doi: 10.1088/1755-1315/355/1/012092.

[14] D. Thakulla, B. Dunn, B. Hu, C. Goad, and N. Maness, "Nutrient solution temperature affects growth and ◦ brix parameters of seventeen lettuce cultivars grown in an NFT hydroponic system," Horticulturae, vol. 7, no. 9, Sep. 2021, doi: 10.3390/horticulturae7090321.

[15] G. Cortella et al., "Temperature control of nutrient solution in floating system cultivation," Appl Therm Eng, vol. 73, no. 1, pp. 1055–1065, 2014, doi: 10.1016/j.applthermaleng.2014.08.068.

[16] Y. Kawasaki, S. Matsuo, K. Suzuki, Y. Kanayama, and K. Kanahama, “Root-zone cooling at high air temperatures enhances physiological activities and internal structures of roots in young tomato plants,” Journal of the Japanese Society for Horticultural Science, vol. 82, no. 4, pp. 322–327, 2013, doi: 10.2503/jjshs1.82.322.

[17] J. Sun, N. Lu, H. Xu, T. Maruo, and S. Guo, “Root zone cooling and exogenous spermidine root-pretreatment promoting Lactuca sativa L. growth and photosynthesis in the high-temperature season,” Front Plant Sci, vol. 7, no. MAR2016, Mar. 2016, doi: 10.3389/fpls.2016.00368.

[18] M. R. Hasan, A. K. M. M. Tahsin, M. N. Islam, M. A. Ali, and J. Uddain, “Growth and Yield of Lettuce (Lactuca Sativa L.) Influenced As Nitrogen Fertilizer and Plant Spacing,” IOSR J Agric Vet Sci, vol. 10, no. 06, pp. 62–71, Jun. 2017, doi: 10.9790/2380-1006016271.

[19] J. He, L. Qin, and S. K. Lee, “Root-zone CO2 and root-zone temperature effects on photosynthesis and nitrogen metabolism of aeroponically grown lettuce (Lactuca sativa L.) in the tropics,” Photosynthetica, vol. 51, no. 3, pp. 330–340, Sep. 2013, doi: 10.1007/s11099-013-0030-5.

[20] H. C. Thompson, R. W. Langhans, A. J. Both, and L. D. Albright, “Shoot and root temperature effects on lettuce growth in a floating hydroponic system,” Journal of the American Society for Horticultural Science, vol. 123, no. 3, pp. 361–364, 1998, doi: 10.21273/jashs.123.3.361.

[21] S. Masaru, M. Uenishi, K. Miyamoto, and T. Suzuki, “Effect of Root-Zone Temperature on the Growth and Fruit Quality of Hydroponically Grown Strawberry Plants,” Journal of Agricultural Science, vol. 8, no. 5, p. 122, Apr. 2016, doi: 10.5539/jas.v8n5p122