Eksakta : Berkala Ilmiah Bidang MIPA
VOLUME 24 NO 04 2023, pp 476-486
ISSN : Print 1411-3724 — Online 2549-7464
DOI : https://doi.org/10.24036/eksakta/vol24-iss04/390

Eksakta
Berkala Ilmiah Bidang MIPA
http://www.eksakta.ppj.unp.ac.id/index.php/eksakta

Article

Effect of Nutrient Solution Temperature and Varieties on Growth and Yield of Lettuce (*Lactuca sativa* L.) with Nutrient Film Technique System

Article Info

Article history :

Received January 10, 2023
Revised June 28, 2023
Accepted July 19,2023
Published December 30, 2023

Keywords :
Asteraceae, growth, solution temperature, root-zone

Aulia Afifah Rachman[1], Kusumiyati[1*], Wawan Sutari[1], Shazma Anwar[2]

[1]Department of Cultivation, Faculty of Agriculture (FAPERTA), Universitas Padjadjaran, Sumedang, Indonesia
[2]Department of Agronomy, The University of Agriculture, Peshawar, 25130, Khyber Pakhtunkhwa, Pakistan

Abstract. Lettuce plants are cool-season leaf vegetables, if grown in areas near the city center with high temperatures can reduce the quantity and quality of the yield. The low temperature in the root zone in the hydroponic system was the solution. This experiment aimed to determine the effect of nutrient solution temperature and variety on the growth and yield of lettuce plants in the nutrient film technique (NFT) system. The experimental design used was a Randomized Block Design with 6 treatments (a combination of solution temperatures 25, 16, and 10 ℃; Red and Green lettuce). The result showed no significant effect of the treatment on the number of leaves 0-20 days after planting (DAP) and root length. Nutrient solution temperature ±10 ℃ gave the best response to the number of leaves (13.08 sheets), plant height (20.80 cm), root volume (18.88 mL), and fresh weight (137.08 g) of green lettuce plants.

Corresponding Author :
Kusumiyati
Department of Cultivation, Faculty of Agriculture (FAPERTA),
Universitas Padjadjaran, Sumedang, Indonesia
Email : kusumiyati@unpad.ac.id

1. Introduction

Lettuce (*Lactuca sativa* L.) is widely consumed worldwide as a salad or eaten directly because it is not bitter and has a crunchy texture [1]. On a global scale, China is a world leader in lettuce production, which can produce four times more [2][3]. The second lettuce-producing country after Cina was

occupied by the United States. The United States successfully harvested 105,000 ha of lettuce worth $3.5 billion USD in 2019 [4].

Climate changes greatly affect crop production, especially when the temperature around the plants increases [5]. In tropical countries like Indonesia generally, lettuce has a life cycle of more than 70 days with conventional cultivation. This can affect the quality and quantity of lettuce so hydroponic cultivation is a solution to this problem. Hydroponics is the cultivation of plants without soil media, but using substrate and water media. After the hydroponic system, growing lettuce takes only 40 days until harvest. In tropical environments, the cultivation cycle of lettuce plants is about 70 days conventionally whereas, with a hydroponic system, lettuce can be harvested at the age of 40 days [6].

The hydroponic system has been widely used in city center areas where the air temperature is high. This condition becomes a challenge in the cultivation of hydroponic lettuce because the air temperature is difficult to control so that resulting in the uncontrolled temperature of the solution in the root zone. Plant growth will be affected if the temperature of the root zone is not controlled. Temperature is the main factor affecting the crop photosynthesis process [7]. Therefore, controlling the temperature in the cultivation of hydroponic lettuce can be done by manipulating the temperature of the solution in the root zone.

The temperature of the root zone in hydroponic cultivation is the temperature of the nutrient solution. The temperature of the root zone is included in the environmental factors that can affect the growth and development of lettuce plants. The temperature in the root zone can affect the growth and chemical composition of various plants [8]. Temperature is an important environmental factor, a factor uniquely related to agricultural production that has a major impact on plant growth, development, and yield [9]. The content of plant secondary metabolites is influenced by environmental factors including climate and ecology, so changes in environmental conditions may cause problems for plant production [10]. Light and temperature are included in climate factors. This factor greatly affects the important parameters of the quality of marketed lettuce. Important parameters in the sale of lettuce, namely color, crispness, aroma, taste, secondary metabolic compounds, and others are strongly influenced by abiotic and biotic factors [11][12]. A root-zone temperature of 28 °C generally resulted in the highest specific leaf area and 32 °C in the lowest [13]. The water absorption of plants depends on the root system, photosynthesis process in lettuce plants decreases when their roots are exposed to hot ambient temperatures due to decreased water absorption by the roots [14][15].

Low temperatures can affect leaf growth. Plants grown in cooler conditions will develop smaller leaves than in warmer temperatures or controls. Leaf growth at low temperatures can result in significant changes in leaf morphology. At 20/15 °C (day/night), the temperature appeared to promote a higher lettuce leaf number than 12/7 °C (day/night) [16]. The 15 °C root zone temperature (RZT) (day/night) gave the maximum yield of red romaine lettuce [16]. Plants can reach their maximum height at 25 °C and weight at 20 °C, while higher temperatures can cause stunted or shortened plant height [13]. Leaf fresh weight at low-temperature treatment in the root zone 5 and 10 °C was significantly reduced compared to 15 and 20 °C [17].

Several factors that can affect the temperature of the nutrient solution include shade, solar radiation, air or ambient temperature, weather, and climate. Higher water temperatures can be caused by increasing air temperature, it occurs in the summer (July-September) [18][19]**.** Therefore, the intensity of sunlight and high air temperature will make the temperature of the nutrient solution high as well. The hot climate in Indonesia will also affect the high temperature of nutrient solutions. As a country located on the equator and an archipelagic country, Indonesia is more vulnerable to climate change and this can cause high water temperatures [20]. Climate change can cause good or bad productivity in lettuce [21].

Lettuce can grow optimally in cool areas, if it is planted in the lowlands, intensive maintenance is needed. The optimal air temperature for lettuce is 17-24 °C [22]. The use of water chillers abroad has been widely used to control the temperature of nutrient solution in hydroponic lettuce cultivation

according to their needs. The water temperature in the nutrient film technique (NFT) tank was cooled and regulated at 18.3 ℃ and 21.1 ℃ using a water chiller [15][23]. The temperature of the nutrient solution can also be controlled using a heating or cooling spiral. The use of water chillers abroad has been widely used to control the temperature of nutrient solution in hydroponic lettuce cultivation. Hydroponic lettuce farmers in Indonesia still rarely use the water chiller because of the high price and difficult availability, but there is still an alternative method that is easy to implement, namely using ice cubes. Putting ice cubes into the nutrient solution can lower the temperature of the solution. Therefore, it is important to know the temperature of the nutrient solution that is suitable for the root zone in increasing the growth, yield, and yield quality of lettuce plants with hydroponic cultivation.

2. Experimental Section

2.1. Materials

The tools used in this experiment are a total dissolved solids (TDS) meter; pH meter; hydrometers; camera; stationary; hacksaw; ruler; Mettler Toledo brand analytical balance type AG254 (Switzerland) and water pump. The materials used in this experiment were rock wool, plastic nursery containers, green (Grand Rapids) and red (Arista) lettuce seeds, water, AB nutrients mixed with leaf vegetables, and ice cubes in 1.5 L plastic bottles. The materials for the NFT hydroponic installation are 2m wood, ultraviolet (UV) plastic, 2.5" and 1.5" PVC pipe, 2.5" and 1" knee (L connection) stop faucet, hubcap 2.5", storage box, pipe glue, 5 L plastic bottle.

2.2. Methods

This experiment was conducted at Bojongloa Kaler District, Bandung City with an altitude of 694 meters above sea level (asl). The experiment was carried out during the dry season, from June to Agustus 2022. The research flowchart is shown in Figure 1.

Red and green lettuce that had been transplanted were treated with solution temperature under 3 conditions. Red and green lettuce that had been transplanted were treated with solution temperature under 3 conditions. First, the nutrient solution contained in the first installation storage box is allowed to obtain a temperature according to environmental conditions ($\pm$25 ℃). Second, the nutrient solution contained in the second installation storage box was treated by adding ice cubes in a plastic bottle until the solution temperature reached $\pm$16 ℃. The volume of ice cubes added to the second installation storage box is 15 L or 10 large plastic bottles (1.5 L per bottle). The time required to reach the temperature of 16 ℃ is 25 minutes. The temperature can last for 102 minutes and it is necessary to add ice cubes every 1 hour.

Third, the nutrient solution contained in the third installation storage box was treated by adding ice cubes in a plastic bottle until the solution temperature reached $\pm$10 ℃. The volume of ice cubes added to the third installation storage box is 15 L or 10 large plastic bottles (1.5 L per bottle), the time needed to reach a temperature of 10 ℃ is 72 minutes. The temperature can last for 149 minutes and the addition of ice cubes needs to be done every 1 hour. The nutrient solution flowed simultaneously to each installation when the temperature of the solution in the storage box is in by each treatment. Treatment was given from 08.00 - 17.00 Western Indonesian Time for 30 days.

Parameters observed were the number of leaves, plant height, root length and volume, and fresh weight. There were 6 treatment combinations, namely A (25 ℃, green lettuce), B (25 ℃, red lettuce), C (16 ℃, green lettuce), D (16 ℃, red lettuce), E (10 ℃, green lettuce), and F (10 ℃, red lettuce). Each treatment was repeated 4 times so that there were 24 experimental units. Each experimental unit consisted of 3 plants, so there were 72 lettuce plants. Data analysis was performed using the Microsoft Excel application and IBM Statistical Product and Service Solutions (SPSS) 25 F test (fisher) 5% significance level.

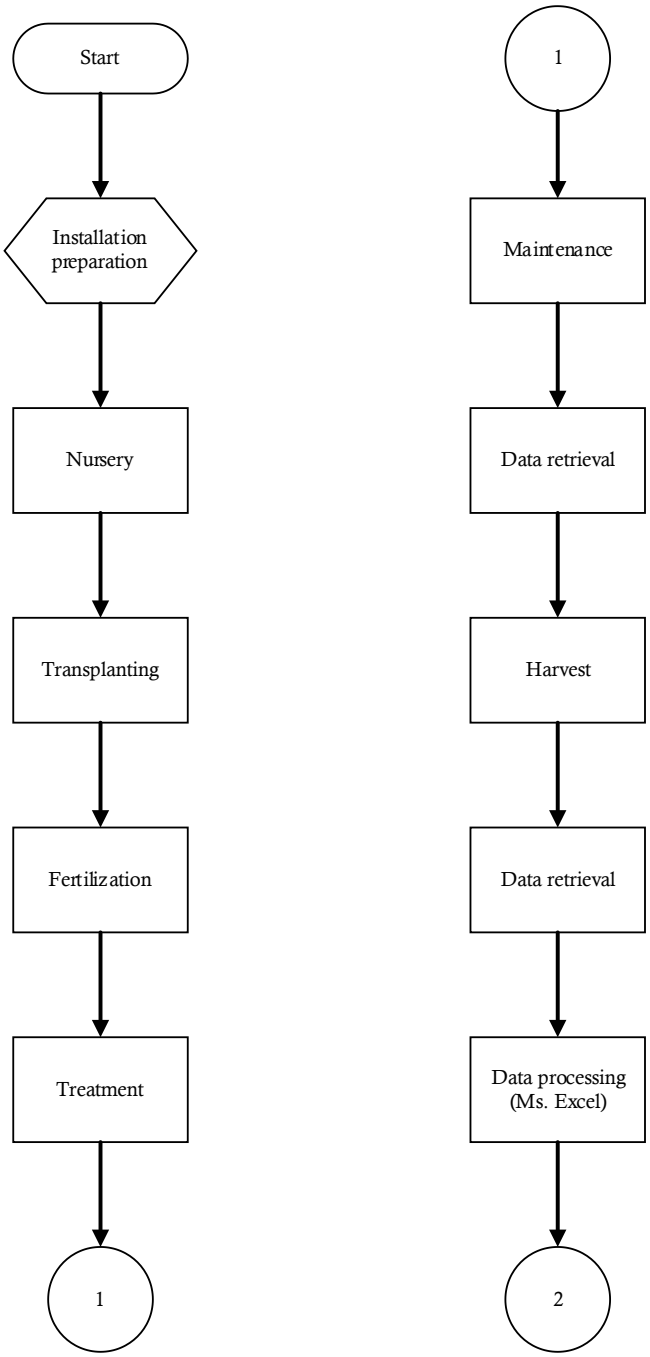

Figure 1. Schematic/flowchart of research

Number one (1) is the next step in treatment. Number two (2) is the next step in data processing (Ms. Excel). Number three (3) is the next step from Duncan's multiple range test. Number four (4) is a non-significant result in the analysis of variance. Y is a sign of a normal or significant result and N is a sign of an abnormal or non-significant result from the test.

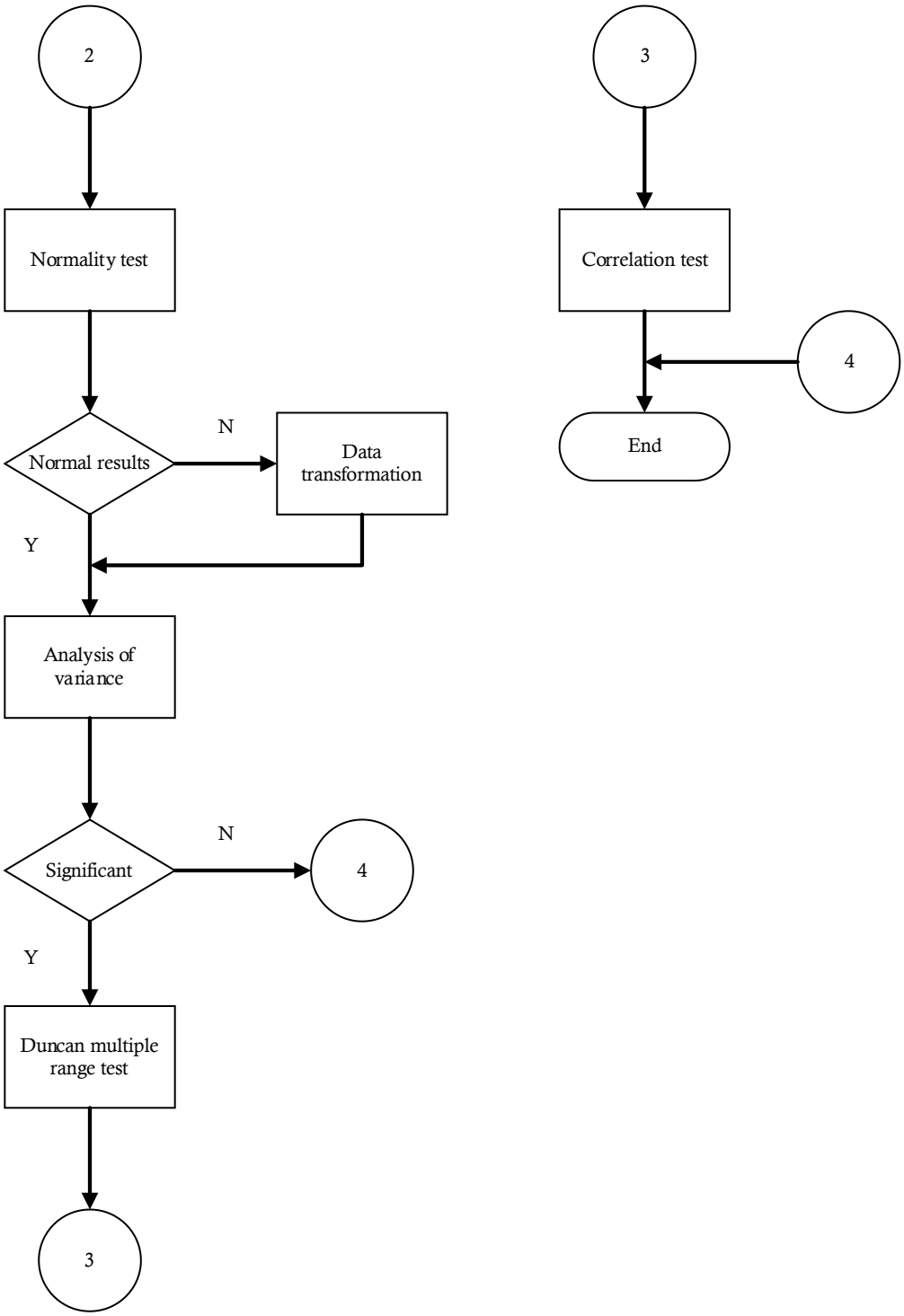

Figure 2. Schematic/flowchart of research

3. Results and Discussion

3.1. Number of Leaves (Sheets)

Based on the results of the analysis of the various effects of nutrient solution temperature and variety on the number of leaves, it shows that there is no significant effect on the number of leaves of lettuce plants at the age of 0–20 DAP. Meanwhile, at the age of 25 and 30 HST, the temperature treatment of the nutrient solution and the variety had a significant effect on the number of leaves of the lettuce plant. At 30 DAP, treatment E (10 ℃, green lettuce) produced a significantly higher number of leaves compared to treatments A (25 ℃, green lettuce), B (25 ℃, red lettuce), C (16 ℃, green lettuce), D (16 ℃, red lettuce), and F (10 ℃, red lettuce) (Table 1).

The nutrient solution temperature of ±10 ℃ gave the best effect on the number of leaves of green lettuce plants. The effect of low nutrient solution temperature was studied on butterhead lettuce, namely, there was a significant increase in canopy diameter, number of leaves, and yield at low rooting temperature (19 ℃) [24]. Based on the experimental results, it is known that the temperature of the nutrient solution of 10–25 ℃ does not affect the number of leaves of red lettuce, whereas in green lettuce it is known that the temperature of the nutrient solution has a better effect on the number of leaves. In the analysis of growth parameters, the leaf area of red lettuce decreased due to the low temperature of the solution in the root area, but there was no significant difference in the number of leaves [25].

Table 1. Effect of nutrient solution temperature and varieties on number of leaves

No	Nutrient Solution Treatment	Number of Leaves (Sheets)
1	A (25 ℃, green lettuce)	10.58 b
2	B (25 ℃, red lettuce)	6.83 a
3	C (16 ℃, green lettuce)	11.50 b
4	D (16 ℃, red lettuce)	7.67 a
5	E (10 ℃, green lettuce)	13.08 c
6	F (10 ℃, red lettuce)	7.33 a

The lower number of leaves of red lettuce compared to green lettuce could be affected by the adaptability of red lettuce in the intermediate plains, causing an interaction between the environment and genotype. The interaction between genotype and the environment can affect the expression of a phenotype and can inhibit plant breeding and cultivar recommendations from the selection process [26].

3.2. Plant Height (cm)

Based on the results of the analysis of variance, it was shown that the temperature of the nutrient solution and the variety had a significant effect on the height of the lettuce plants from 0 to 30 DAP. Treatments A (temperature ±25 ℃, green lettuce), C (temperature ±16 ℃, green lettuce), and E (temperature ±10 ℃, green lettuce) at 25 DAP resulted in significantly higher growth in plant height compared to the treatment B (temperature ±25 ℃, red lettuce), D (temperature ±16 ℃, red lettuce), and F (temperature ±10 ℃, red lettuce).

Green lettuce plant height at all nutrient solution temperatures was higher than red lettuce. The temperature of the nutrient solution of ±16 ℃ resulted in a significantly higher plant height of red lettuce compared to the temperature of the nutrient solution of ±10 ℃, although the two treatments were not significantly different from the temperature of the nutrient solution of ±25 ℃. At 30 DAP, treatments A (25 ℃, green lettuce), C (16 ℃, green lettuce), and E (10 ℃, green lettuce) resulted in

significantly higher growth in plant height compared to the treatment B (25 ℃, red lettuce), D (16 ℃, red lettuce), and F (10 ℃, red lettuce) (Table 2).

Judging from these differences, it shows that in green and red lettuce plants, plant height is also influenced by genetic factors and their adaptability. In previous studies, plant height was influenced by variety, for example, the height of the Salanova type of lettuce "Sweet Crisp Green" was higher than "Oakleaf Red" and "Butter" [15].

Table 2. Effect of nutrient solution temperature and varieties on plant height

No	Nutrient Solution Treatment	Plant Height (cm)
1	A (25 ℃, green lettuce)	18.66 b
2	B (25 ℃, red lettuce)	13.23 a
3	C (16 ℃, green lettuce)	20.80 b
4	D (16 ℃, red lettuce)	13.60 a
5	E (10 ℃, green lettuce)	20.80 b
6	F (10 ℃, red lettuce)	11.67 a

Based on the variety description, the height of green lettuce plants when harvested can reach 18.5–22.4 cm. This shows that the height of green lettuce plants at 30 DAP in all nutrient solution temperature treatments was in accordance with the optimum values, namely 18.66 and 20.8 cm. Red lettuce plant height at optimum ambient temperature can reach the range of 19.30–21.70 cm. The average value of red lettuce plant height in treatments B (25 ℃, red lettuce), D (16 ℃, red lettuce), and F (10 ℃, red lettuce) was 13.23; 13.60; 11.67 cm respectively.

Therefore, the height of red lettuce plants in all treatments did not match the optimum height. This can be caused by the air temperature does not support the growth of red lettuce plants. Not only temperature in the root zone area but also ambient air temperature can affect plant growth [27]. Based on the description of the variety, it also shows that the adaptation area of Arista red lettuce is more suitable for planting in the highlands with low temperatures, while the experimental site is in the lowlands with high temperatures.

3.3. Root Length (cm) and Volume (mL)

The results of the analysis of variance of the effect of nutrient solution temperature and variety on root length were not significantly different, while for root volume the results showed significant differences. The root length which was not significantly different in all treatments was probably due to the roots being in the installation pipe filled with a nutrient solution so that the root growth was more on the lateral side which caused the root volume to increase. In contrast to plant roots that are in the soil, namely their growth depends on the direction of water availability.

Based on the results of Duncan's advanced test on root volume, it showed that treatments A (25 ℃, green lettuce), C (16 ℃, green lettuce), and E (10 ℃, green lettuce) produced root volumes that significantly higher compared to treatment B (25 ℃, red lettuce), D (16 ℃, red lettuce), and F (10 ℃, red lettuce) (Table 3).

Table 3. Effect of nutrient solution temperature and varieties on root length and volume

No	Nutrient Solution Treatment	Root Length (cm)	Root Volume (mL)
1	A (25 ℃, green lettuce)	46.37 a	18.33 b
2	B (25 ℃, red lettuce)	43.26 a	5.58 a
3	C (16 ℃, green lettuce)	38.74 a	18.00 b
4	D (16 ℃, red lettuce)	44.11 a	8.28 a
5	E (10 ℃, green lettuce)	39.43 a	18.88 b
6	F (10 ℃, red lettuce)	37.68 a	7.34 a

The temperature of the nutrient solution of 10–25 ℃ did not show a significant difference in the root volume of green and red lettuce plants, respectively. The root volume of green lettuce plants at a nutrient solution temperature of 10–25 ℃ resulted in a significantly higher root volume compared to the root volume of red lettuce plants. This is consistent with the fresh weight of green lettuce plants which is also higher than red lettuce and there is a positive correlation between the root volume parameter and plant fresh weight of 0.953. The root volume is measured to find out how much the roots are able to reach or get nutrients and water.

3.4 Fresh Weight (g)

Based on the results of the analysis of variance, it can be stated that the temperature treatment of the nutrient solution and the variety significantly affected the fresh weight of the plants. Treatments A (25 ℃, green lettuce), C (16 ℃, green lettuce), and E (10 ℃, green lettuce) resulted in significantly higher plant fresh weight compared to treatment B (25 ℃, red lettuce), D (16 ℃, red lettuce), and F (10 ℃, red lettuce) (Table 4). The temperature of the nutrient solution of 10–25 ℃ did not show a significant difference in the fresh weight of green and red lettuce plants, respectively.

Table 4. Effect of nutrient solution temperature and varieties on fresh weight

No	Nutrient Solution Treatment	Fresh Weight (g)
1	A (25 ℃, green lettuce)	139.41 b
2	B (25 ℃, red lettuce)	33.91 a
3	C (16 ℃, green lettuce)	125.79 b
4	D (16 ℃, red lettuce)	37.10 a
5	E (10 ℃, green lettuce)	137.08 b
6	F (10 ℃, red lettuce)	30.29 a

The treatment that gave higher plant fresh weight was a combination treatment of nutrient solution temperature with green lettuce, while the lower one was a treatment combination of nutrient solution temperature with red lettuce. This proves that the temperature of the nutrient solution does not affect the fresh weight of green and red lettuce plants. Green lettuce can grow well at all temperature treatments of nutrient solutions and is not affected by the ambient temperature in the experimental site. Although the description of the green lettuce variety (grand rapids) states that green lettuce can adapt well to an altitude of 900–1,200 m asl, the growth, and development of green lettuce in the experimental field (694 m asl) remains optimal in terms of fresh weight has a value of 125.79-139.41 g exceeding the potential in the description of the plant, which is in the range of 116-128.2 g.

Green lettuce can grow well at all temperature treatments of nutrient solutions and is not affected by the ambient temperature in the experimental site. The low nutrient solution temperature also did not inhibit the growth of green lettuce plants. Cooling around the roots at 20 ˚C with ambient temperature conditions (24 ˚C – 38 ˚C) can increase the fresh weight of lettuce plants grown aeroponically in tropical greenhouses [28].

The fresh weight of red lettuce plants was also not affected by the temperature of the nutrient solution but by the air temperature in the experimental field. According to the variety description, it is stated that the Arista variety is suitable for planting in the highlands. If growth is optimal, fresh weight per plant can reach 520.35–656.60 g. This shows that the red lettuce variety Arista cannot adapt to land with high air temperatures so the low nutrient solution temperature does not affect plant fresh weight. In contrast, this research stated that the fresh weight of lettuce plants was greatly depressed by the 5 ˚C temperature treatment and the weight was only about 25% of the lettuce plants treated at 20 ˚C [29]. Under conditions of favorable altitude and air temperature, the temperature of the nutrient solution may have an effect on the fresh weight of red and green lettuce plants.

The low fresh weight of red lettuce plants can also be caused by the lower number of leaves, plant height, and root volume compared to green lettuce. Based on the correlation test between plant fresh weight at 30 HST and number of leaves (0.931), plant height (0.901), and root volume (0.953) showed a positive and strong correlation. Therefore, if the number of leaves, plant height, root volume, and water content of red lettuce plants are low, the plant's fresh weight will also be low.

Varieties of lettuce plants can also be the cause of differences in the fresh weight of green and red lettuce plants. There are large differences in growth characteristics, including size index and fresh weight among varieties of various types of plants, these differences are associated with genetic diversity [30].

4. Conclusion

There is an influence of nutrient solution temperature and variety on the parameters of the number of leaves (age 25 and 30 DAP), plant height (age 0-30 DAP), root volume, and fresh weight of lettuce plants in the hydroponic nutrient film technique. Nutrient solution temperature $\pm$10 ℃ gave the best response to the number of leaves (13.08 sheets), plant height (20.80 cm), root volume (18.88 mL), and fresh weight (137.08 g) of green lettuce plants.

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