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RESEARCH

Effects of Variable Electrical Conductivity Levels in Hydroponic Nutrient Solutions on Morphological and Physiochemical Characteristics of Cucumber Plants in Advanced Greenhouse Cultivation

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Abstract

Cucumber (*Cucumus sativus* L.) is a fruit of the Cucurbitaceae family that is refreshing, low in calories, and offers various health benefits due to its rich nutritional profile. However, high-tech hydroponic greenhouse production of cucumber is nutrient-intensive and requires efficient management of electrical conductivity (EC) in the growing medium. In this study, three different EC levels (1.3, 2.6, and 3.6 dS/m) were applied to the nutrient medium of hydroponically grown Lebanese and Continental varieties of cucumber. The experiment did not have a significant impact on the number of fruits (p=0.744, p=0.163) or leaves per plant (p=0.252, p=0.377) at varying EC levels. However, in the Continental variety, pH (0.001***) and osmolality (0.005**) were significantly different among the three varied EC levels. High EC levels in the nutrient medium resulted in reduced TSS, pH, and osmolality of the fruit juice. Although the plants grown in low EC conditions produced almost the same number of fruits and leaves per plant as those grown in optimal EC conditions (2.6 dS/m), the physio-chemical attributes of the cucumbers were of inferior quality.

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Statement of Sustainability: Precise nutrient management is essential for sustainable agriculture. Our research aims to investigate the impact of the electric conductivity of nutrient solutions on the morphological and physiochemical traits of cucumber plants. We strive to establish a tailored approach to nutrient management strategies, reducing excesses that can have negative effects on crop quality, performance, and environmental integrity. The approach aligns with sustainable practices by addressing the imperative need to curtail the over-application of chemical fertilizers. This research focuses on identifying the optimal EC levels that foster crop development while promoting environmental stewardship and mitigating carbon footprint. The findings make a significant contribution towards sustainable and resilient agricultural systems.

1. Introduction

Cucumber (*Cucumis sativus* L. ssp) is a widely cultivated vegetable in the gourd family, known for its crisp texture, mild flavor, and high water content. It has been a culinary staple worldwide for centuries (Nurwitasari et al., 2021; Ugwu and Suru, 2021). The high water content, which is more than 95%, and the good concentration of nutrients, including sodium, magnesium, potassium, sulfur, silicon, and fluorides, make it ideal for human health (Pal et al., 2020). These nutrients help to keep the body hydrated and enhance the proper function of vital organs such as the kidneys, heart, and lungs. Cucumbers are known for their anti-inflammatory properties due to their high alkalinity content, which helps to maintain a balanced pH level in the human body (Murad and Nyc, 2016). In addition, its antioxidative properties may aid in the prevention of cancer and autoimmune diseases that are often linked to oxidative stress (James, 2023). The High-Tech Greenhouse, a protected cropping system, is a modern method of cultivating cucumbers that offers superior yield and quality. However, greenhouse cucumber production is nutrient-intensive and often faces abiotic stress, such as salinity stress due to excessive chemical fertilizer application (Bayoumi et al., 2021). Increasing fruit yield and quality is crucial for greenhouse production systems to meet the demand of the expanding fresh fruit market (Díaz-Galián et al., 2021; Wu et al., 2020). Soil salinity is a significant abiotic stress, with affected areas increasing by 26% globally from 2000 to 2016 (Ivushkin et al., 2020). Currently, over 1 billion hectares are impacted by soil salinity, mainly in arid regions (Bayoumi et al., 2021). It is crucial to address and understand the challenges posed by increasing salinization on a global scale. Potassium is a crucial element that helps maintain a proper balance of nutrients in the nutrient solution (Sardans and Peñuelas, 2021). Its synergistic and antagonistic effects on other ions in hydroponic nutrient solutions create a balancing effect that is suitable for the overall growth and development of cucumber plants (Çalişkan and Çalişkan, 2019). High-tech greenhouse production of cucumbers using a soilless cultivation system has become increasingly popular. To avoid water loss and environmental issues, drained water is commonly recirculated. However, this can lead to increased nutrient levels and higher electric conductivity (EC), causing detrimental abiotic stress to the cucumber plant. According to Guerrero et al. (2012), cucumber growth is significantly affected when the EC level exceeds 1.3 dS/m. Calibrating EC can help maintain salt stress and water availability, as well as balance vegetative and generative growth ratios (Tallarita et al., 2023). However, an increase in EC of the nutrient solution may interfere with plant morphology, reduce leaf area, and root and shoot length, and ultimately decrease the yield of the cucumber plant (Farid et al., 2020; Łaźny et al., 2022). Higher EC of the nutrient medium can interfere with plant nutrient uptake due to changes in pH levels (Msimbira and Smith, 2020). Ding et al. (2018) reported that a decrease in pH led to a gradual increase in chlorophyll content in leaves, as well as an increase in nutrient uptake of Mg, Zn, and Ca in Pokchoya. This finding was also observed in rock melon by Zulkarami et al. (2010). However, no specific research has been conducted on hydroponically grown cucumber crops. As a crucial component of the hydroponic system, maintaining a stable EC level is essential for balanced nutrient uptake, growth, and development of cucumbers. The objective of this study is to investigate the impact of different EC levels on the morphological and physiochemical characteristics of two cucumber varieties.

2. Materials and Methods

2.1. Experimental Design

The experiment was conducted at the National Vegetable Protected Cropping Centre (NVPCC) at Western Sydney University (WSU), Richmond, Australia. Two cucumber varieties, Lebanese (V1) and Continental (V2), were grown at three different levels of EC to assess the impact of balanced nutrient media on the growth and yield of both varieties. The nutrient medium's EC was maintained at three different levels: T1= 1.3 dS/m, T2=2.6 dS/m, and T3= 3.6 dS/m. To determine the average number of fruits and leaves per plant, the number of fruits and leaves was counted randomly from each EC level.

2.2. Physiochemical Analysis

The pH of the cucumber juice was measured using a pH meter, which is an efficient and accurate instrument. The probe contains a glass electrode that is sensitive to the hydrogen ion (H^+). The total soluble solids (TSS) of the fruit juice are a measure of the refractive index of the solution. The TSS value in degree brix was determined using a hand-held refractometer (Aziz et al., 2021). The refractive index of the solution was determined by comparing the speed of light passing through the solution to the speed of light in the air (Paul et al., 2010). To avoid contamination, the refractometer was cleaned with double distilled water, and sterilized paper was used to wipe off any moisture after each reading. The osmolality of the cucumber juice was determined using a vapor pressure osmometer, which is based on the reduction in vapor pressure that occurs when solutes are added to a solvent (Larkins and Thombare, 2022).

2.3. Chlorophyll Content Measurement

The chlorophyll content in cucumber leaves was measured at three different ECs using a spectrophotometer. The standard protocol adopted by Shukla et al. (2023) was followed. To calculate the chlorophyll content, the absorbance value obtained from the spectrophotometer was used, following the calculation method described by Gai et al. (2023).

$$\text{Chlorophyll A (mg/g)} = 12.7(\text{A663}) - 2.69(\text{A645}) \times \text{V}/1000 \times \text{W}$$

$$\text{Chlorophyll B (mg/g)} = 22.9(\text{A645}) - 4.68(\text{A663}) \times \text{V}/1000 \times \text{W}$$

$$\text{Total chlorophyll (mg/g)} = 20.2(\text{A645}) + 8.02(\text{A663}) \times \text{V}/1000 \times \text{W}$$

Where A is the absorbance at a specific wavelength (nm), V is the final volume of chlorophyll extract in 80% acetone, and W is the weight of the fresh tissues extracted.

2.4. Statistical Analysis

The data were transferred to Microsoft Excel (Microsoft Corp., USA) and R-Studio (Version 4.2.3, Boston Massachusetts, USA) for statistical analysis. Before data analysis, necessary transformations were made, and normality and homogeneity were checked. Analysis of Variance (ANOVA) and LSD tests were conducted at a 5% level of significance to identify the distinct impact of EC on the morphological and physiological traits of cucumbers. The Pearson correlation coefficient was calculated to better understand the interrelationship between the different traits.

3. Results

3.1. Average Number of Fruits and Leaves of Cucumber

The study found that the average number of fruits per plant did not show any statistically significant difference across three different EC levels for both Lebanese and Continental varieties of cucumber (p=0.744, p=0.163; Table 1). The Lebanese variety had the highest number of fruits at T2 (32.17), followed by T3 (31.5) and T1 (31), respectively. In the case of the Continental variety, T1 had the highest number of fruits (22.7), followed by T3 (20.7) and T2 (19.72), respectively (Figure 1). The Lebanese variety exhibited a higher fruit yield, with up to 40% more fruit than the continental variety, and this difference was statistically significant (p<0.001***). Additionally, the average number of leaves increased gradually with the EC level, peaking at T3 (105.5) for the Lebanese variety. In contrast, the Continental variety had its highest and lowest average number of leaves at T3 (90.17) and T2 (84.67), respectively. The average number of leaves per plant was not statistically different between the Lebanese and Continental varieties across all three EC levels (p=0.252, p=0.377). Although the Lebanese variety had a slightly higher number of leaves (up to 15%) than the Continental variety, this difference was not statistically significant (p=0.262). The statistical analysis revealed significant results for the interaction between EC and Variety in both the average number of fruits and leaves (p<0.001***, p=0.003**).

Table 1. Result of ANOVA analysis of Plant parameters responses at different EC levels and Variety, and their interactive impact.

Plant trait	EC/V1		EC/V2		Variety		EC × Variety	
	F	P	F	P	F	P	F	P
Average Number of Fruits	0.301	0.744	2.049	0.163	157.8	<0.001***	33.16	<0.001***
Average Number of Leaves	1.514	0.252	1.042	0.377	17.06	0.262	4.674	0.003**
Total chlorophyll content	1.482	0.242	0.609	0.55	3.144	0.0806#	1.34	0.258
Chlorophyll A Content	2.637	0.087#	0.897	0.417	1.309	0.257	1.475	0.21
Chlorophyll B Content	0.632	0.512	0.683	0.512	2.555	0.114	0.593	0.705
pH	0.012	0.988	9.739	<0.001***	2.213	0.141	5.229	<0.001***
Total Soluble Solid (TSS)	3.226	0.0508#	0.14	0.87	3.637	0.06#	1.738	0.138
Osmolality	3.26	0.051#	6.298	0.005**	3.803	0.055*	4.707	<0.001***

***significant at $p \le 0.001$, **significant at $p \le 0.01$, *significant at $p \le 0.05$, and # represent marginal non-significance ($p < 0.10$).

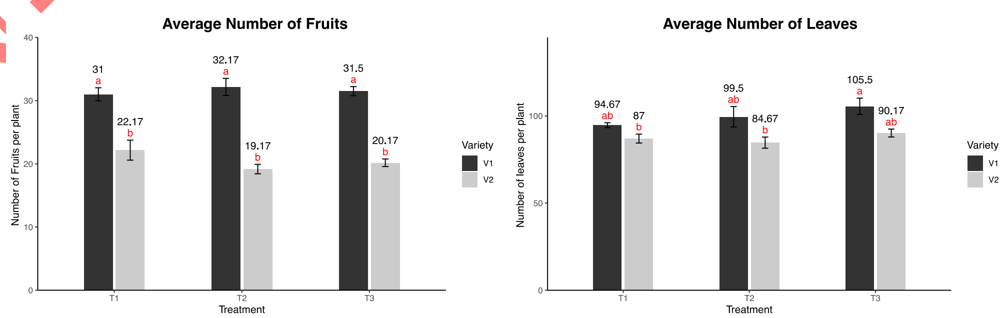

Figure 1. The average number of fruits and leaves at three different electric conductivity levels (V1=Lebanese, V2=Continental; different letters signify a significantly different group at a 5% significance level).

Table 2. Results of least significant difference (LSD) test (*p*-value) of different morphological and physiochemical traits of cucumber.

Traits	No of Fruits	No of Leaves	Total Chlorophyll	Chlorophyll a	Chlorophyll b	pH	TSS	Osmolality
Lebanese (V1)								
T2-T1	0.451	0.450	0.778	0.851	0.536	0.891	0.098	0.082#
T3-T1	0.745	0.103	0.193	0.071#	0.965	0.992	0.625	0.064#
T3-T2	0.665	0.351	0.116	0.068#	0.565	0.899	0.056#	0.842
LSD Value	3.214	13.293	2.781	1.818	1.814	0.503	0.378	75.179
CV	8.277	10.814	45.512	57.98	60.916	9.962	11.99	35.313
Continental (V2)								
T2-T1	0.065	0.551	0.882	0.852	0.961	0.514	0.875	0.443
T3-T1	0.205	0.421	0.389	0.299	0.746	<0.001***	0.723	0.061#
T3-T2	0.517	0.171	0.314	0.223	0.709	0.002**	0.608	0.002**
LSD Value	3.217	8.151	3.993	2.474	2.679	0.614	0.426	72.627
CV	12.752	7.590	52.923	66.339	70.168	11.64	12.787	29.014

***significant at $p \leq 0.001$, **significant at $p \leq 0.01$, *significant at $p \leq 0.05$, and # represent marginal non-significance ($p < 0.10$).

3.2. pH and TSS of Fruit Juice of Cucumber

In the continental cucumber variety, there was a significant difference in pH levels among the different EC levels (*p*<0.001***, Figure 2). The juice produced at T3 displayed a significant difference in pH compared to T1 (*p*<0.001***, Table 2) and T2 (*p*=0.002**). The pH values recorded were 6.82, 6.63, and 5.59 at T1, T2, and T3, respectively. It is worth noting that the pH at T3 was markedly lower than that observed at T1 and T2. The pH of the juice decreased moderately as the EC of the nutrient medium increased. In contrast, there was no significant difference in pH levels observed across the T1, T2, and T3 treatments within the Lebanese cucumber variety (*p*=0.988), with pH values of 6.07, 6.1, and 6.07, respectively. Statistical analyses showed no significant difference in pH levels between the continental and Lebanese cucumber varieties (*p*=0.141). The continental variety did not show any statistically significant differences in TSS at the three distinct EC levels (*p*=0.87). Similarly, the Lebanese variety did not show any significant differences in TSS at the three different EC levels, although the difference was very narrow (*p*=0.058#). The highest TSS for both varieties was reported at T2, with 4.03 and 4.06 o Brix for the Lebanese and Continental varieties, respectively. Although the TSS level of the Continental variety was slightly higher than that of the Lebanese variety, there was no significant difference in the TSS levels of the fruit juice between the two cucumber varieties across the three EC treatments (*p*=0.06).

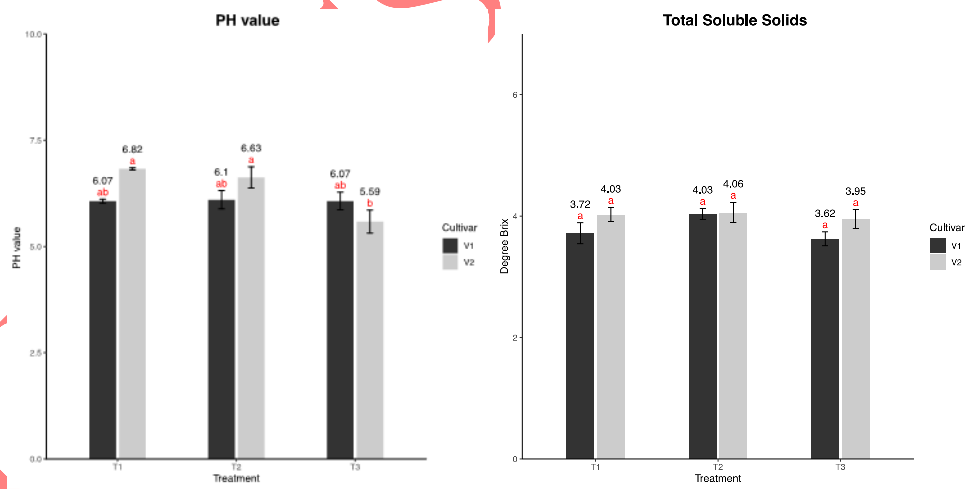

Figure 2. pH and TSS of fruit juice of Lebanese and Continental variety of cucumber at three different EC levels (V1=Lebanese, V2=Continental; different letters signify a significantly different group at a 5% significance level).

3.3. Osmolality of Fruit Juice and Chlorophyll Content in Leaves of Cucumber

The chlorophyll content in cucumber leaves did not vary significantly among the three different EC levels. In the Continental variety, the highest total chlorophyll content was observed at T3 (10.32 mg/g), followed by T1 (8.61) and T2 (8.32), with no significant difference (*p*=0.55). A similar trend was observed in the Lebanese variety, where T3 (8.7 mg/gm) had a comparatively higher total chlorophyll content but was not significantly different (*p*=0.242, Table 2). The chlorophyll content of the Continental variety was slightly higher than that of the Lebanese variety, but the difference was not statistically significant (*p*=0.0806#). The Continental variety showed a similar trend in terms of chlorophyll-a content, with the highest at T3 (5.42 mg/g). However, there was no significant difference among the three different EC levels (p=0.417). The Lebanese variety showed a gradual increase in chlorophyll a content with the increase in EC, reaching its highest level at T3 (4.96 mg/gm) (Figure 3A-3B). The difference in chlorophyll a content in the Lebanese variety was not statistically significant (p<0.10). Although no significant difference in chlorophyll b content was observed in the continental variety across the three different EC levels (p=0.512), the chlorophyll b content was highest at T3 (4.91 mg/g). In the Lebanese variety, higher chlorophyll b content was measured at T1 (3.78 mg/gm) with no significant difference (0.512). Although the Continental variety exhibited greater concentrations of chlorophyll a and chlorophyll b compared to the Lebanese variety, the differences were not statistically significant (p=0.257 for chlorophyll a, p=0.114 for chlorophyll b). Additionally, the interaction between EC levels and variety did not yield a significant result (p=0.21 for chlorophyll a, p=0.705 for chlorophyll b).

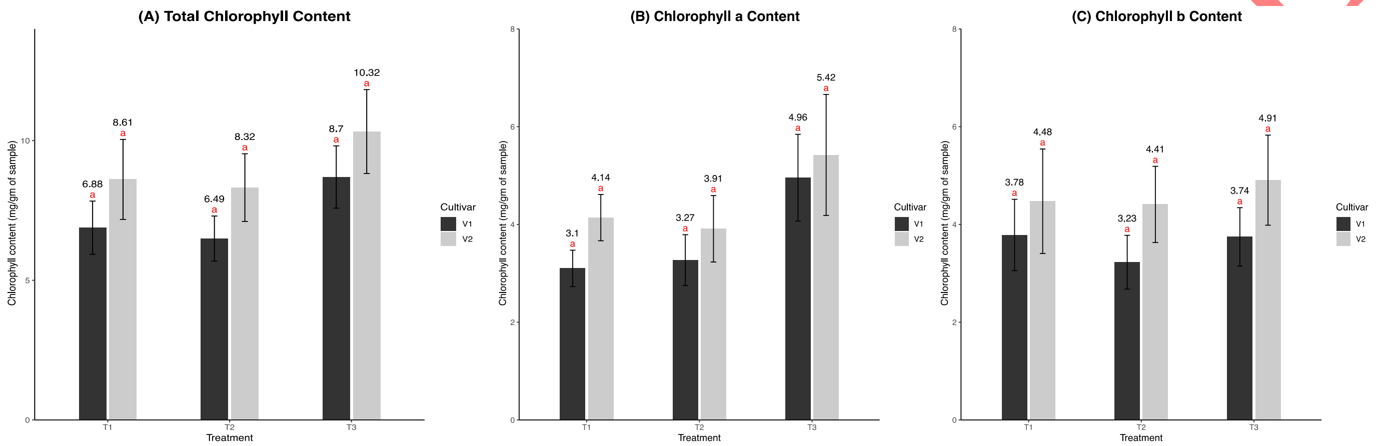

Figure 3. (A) Total chlorophyll content, (B) chlorophyll a content, and (C) chlorophyll b content of leaves of Lebanese and Continental cucumber at three different EC levels (V1=Lebanese, V2=Continental; different letters signify a significantly different group at a 5% significance level).

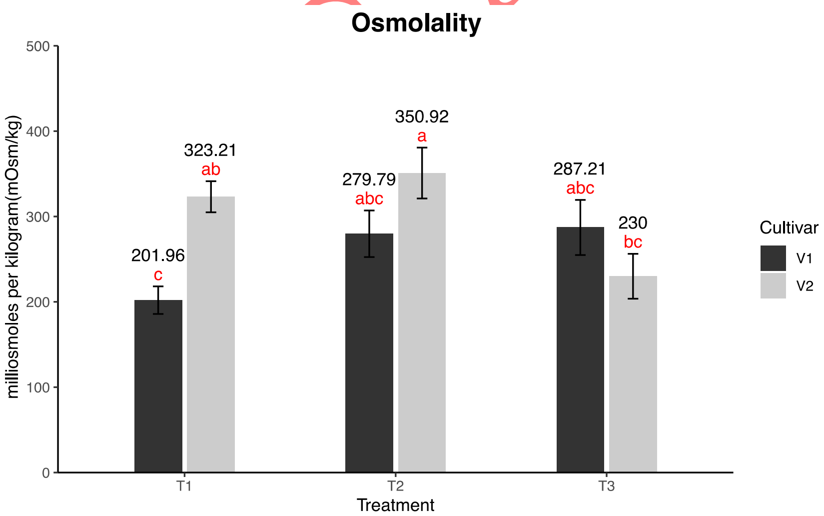

Figure 4. The osmolality of cucumber fruit juice at three different levels of EC (V1=Lebanese, V2=Continental; different letters signify a significantly different group at a 5% significance level).

The osmolality of continental fruit juice varied significantly at three different EC levels (p=0.005**). Figure 4 shows that the osmolality of juice was highest at T2 (350.92) and significantly different from T3 (P=0.002**, Table 2). However, the osmolality of Lebanese cucumber fruit did not show significant differences at varying EC levels (p=0.051#). In the Lebanese variety, there was a noticeable increase in osmolality as EC levels increased, with the highest osmolality recorded at T3. The continental variety also showed higher osmolality compared to the Lebanese cucumber, but the difference was not statistically significant (p=0.055*). The statistical analysis revealed a significant interaction between EC and variety (p<0.001***).

3.4. Correlation Between Different Physiological Parameters of Cucumber

Table 3 shows the correlation coefficient of different parameters measured in this research. The number of fruits and leaves of cucumber had a positive correlation coefficient of 0.604***. Total chlorophyll content in leaves had a positive correlation with chlorophyll A and chlorophyll B content, with correlation coefficients of 0.775*** and 0.786***, respectively. However, other parameters did not show any statistically significant correlation, including pH, TSS, and osmolality. Therefore, these parameters were independent of other parameters.

Table 3. Correlation between different physiological and morphological traits of cucumber.

Plant traits	No of Fruits	No of Leaves	pH	TSS	Osmolality	Total Chlorophyll	Chlorophyll A	Chlorophyll B
No of Fruits	1							
No of Leaves	0.604***	1						
pH	0.061	0.014	1					
TSS	-0.165	-0.115	0.216	1				
Osmolality	0.056	0.221	0.101	0.142	1			
Total chlorophyll	-0.016	-0.036	-0.045	0.066	0.072	1		
Chlorophyll A	0.072	-0.147	-0.056	-0.053	-0.060	0.775***	1	
Chlorophyll B	-0.096	0.089	-0.014	0.154	0.169	0.786***	0.219	1

***significant at $p \leq 0.001$, **significant at $p \leq 0.01$, and *significant at $p \leq 0.05$.

4. Discussion

Two varieties of cucumber, Lebanese and Continental, were grown hydroponically in a high-tech greenhouse system to evaluate the impact of EC and varietal choices on their morphological and physiological traits. The results showed that these attributes are dependent on the EC and variety of cucumbers. The Lebanese variety has been reported to have a higher average number of fruits per plant compared to the Continental variety. This difference may be influenced by the genetic constitution of the crop variety (Ohiaeri and Akor, 2023). Lebanese cucumbers, also known as mini cucumbers, are smaller in size than Continental cucumbers but have a higher yield (Badgery-Parker et al., 2015; Burt, 2007). The Lebanese variety may have a larger average number of fruits due to a higher number of leaves per plant. This is because there is a strongly positive correlation (r=0.604***) between the leaves and fruits. Previous studies have reported that the source (leaf)/sink (fruit) relationship affects the yield and quality of crops, such as apples and blueberries. In these cases, leaves act as an alternative source of carbon for fruits (Baïram et al., 2019). However, according to Burt's (2007) report, the yield of the Continental variety was almost three times greater than that of the Lebanese variety due to its larger fruit size. Although there was no significant difference in the number of fruits and leaves between the two varieties with varied EC levels (concentration of salt and other electrolytes), their interaction was significant. Zulkarami et al. (2010) found no significant difference in leaf area index and number of leaves at varying EC levels in cucumbers. In contrast, Irawati, Sasmita, and Padmini (2023) observed that varying EC levels significantly affected leaf area and plant height in hydroponically grown watermelon, but not fruit weight per plant.

The T2 EC level Lebanese variety produced an average of 40% more fruits than the other interactions. This finding is consistent with the results of lettuce grown under greenhouse conditions, where the EC-variety interaction was crucial in determining overall yield (Sublett et al., 2018). Additionally, increasing the EC level from optimum to high levels was found to reduce fruit weight or yield (Zulkarami et al., 2010). Increased EC in the nutrient medium resulted in a reduction of bulb length, water uptake, nutrient use efficiency, and total fresh mass of hydroponically grown chives (Silva et al., 2023). This may be due to poor nutrient absorption caused by salinity or osmotic stress (Alsaeedi et al., 2019). The increase in EC reportedly alters the pH of the nutrient medium, which interferes with plant nutrient uptake. The concentration of nitrogen in cucumber fruit decreases as the pH of the nutrient solution increases (Blanchard et al., 2020; Ghehsareh and Samadi, 2011). The pH of the soil or nutrient media is a crucial factor that determines nitrogen supply and may reduce yield (Lin et al., 2023).

The quality, postharvest life, and consumer preference of cucumber fruit are largely determined by its pH, TSS, and osmolality. The dry matter content and TSS can be used as indicators of shelf-life, which can help reduce postharvest losses (Valverde-Miranda et al., 2021). The T2 EC level resulted in the highest soluble solids for both varieties, but there was no significant difference in the TSS of fruit when considering varied EC, variety, and their interaction (Table 1). Although statistical significance was missed by a narrow margin (p=0.0508) in the Lebanese variety, we can assume that EC had indirectly influenced the TSS. Lu et al. (2022) obtained results that contradict this statement. Specifically, they found that the TSS of cucumber at T2 (1st stage = 1.5 mS/cm, 2nd stage = 3 mS/cm, 3rd stage = 4.5 mS/cm) and T4 (1st stage = 1.5 mS/cm, 2nd to 3rd stage = 4.5 mS/cm) were significantly different from the other five treatments, increasing the TSS by 9.1% and 9.8%, respectively. Higher EC levels during the later stage of the life cycle appear to improve TSS, highlighting the importance of balanced and calibrated EC levels in the nutrient medium. The pH of cucumber juice was significantly different for the continental variety at varied EC levels, indicating a potential impact of EC on fruit acidity. As EC increased from T2 to T3, there was a significant decline in pH level. Greenhouse-cultivated tomatoes showed a similar result where increasing EC levels from low to high alleviated the pH of fruit juice (Cliff et al., 2012). The concentration of Mg and Zn decreases in the crop under lower pH and augmented EC (pH 4.5 and EC 3.4 dS/m) (Gillespie et al., 2021), which may be the reason behind the decrease in the pH of cucumber juice at increased EC levels since Mg is the major alkalizing ion in the crop (Msimbira and Smith, 2020; Rengel et al., 2015). The impact of different EC levels and the interaction between EC and variety on the osmolality of cucumber juice was significant. Osmolality is a measure of the concentration of solutes, including salts, sugars, and other particles, in a solution. Increasing EC from 2.3-4.5 to 2.5-5.1 dS/m resulted in a 21% increase in the EC of the fruit, which is an important attribute for flavor and consumer satisfaction. However, higher EC levels were found to cause a reduction in sugars, acids, and nutrients, including Ca and Mg (Agius et al., 2022; Gillespie et al., 2021), which may explain the decline in osmolality observed when EC was increased from 2.6 to 3.6 dS/m. Therefore, TSS, pH, and osmolality are important physiological traits of the cucumber crop that are influenced by various levels of EC. An EC level of 2.6 dS/m resulted in optimum TSS, pH, and osmolality.

Although the total leaf chlorophyll, chlorophyll a, and chlorophyll b content gradually increased with an increase in the EC level from low to high, there was no statistically significant difference between the chlorophyll content at the three different EC levels. Similar results were obtained by Ding et al. (2018) in Pakchoi (*Brassica campestris* L. ssp), where the leaf relative chlorophyll content moderately increased as the EC of the nutrient medium increased without any statistically significant difference among the EC treatments. Meanwhile, both high and low EC resulted in a decrease in the leaf net photosynthetic rate, stomatal conductance, and transpiration rate, as reported by Ding et al. (2018). This suggests that although the chlorophyll content in leaves increased, the photosynthetic efficiency decreased. The study found no significant difference in chlorophyll content between continental and Lebanese varieties of cucumber, indicating that genetic constituents did not impact the chlorophyll content. The concentration of nitrite and nitrogen uptake by the plant are the determining factors for the chlorophyll content in the plant (Muhammad et al., 2022; Chen et al., 2024). Ding et al. (2018) found that the nitrite content was higher in crops subjected to higher EC levels, resulting in a gradual increase in chlorophyll content. However, higher EC levels accounted for lower photosynthetic efficiency, which can negatively impact the yield and quality of the fruit. Of the three different EC levels tested, it appears that neither low (1.3 dS/m) nor high (3.6 dS/m) EC are favorable for the physio-chemical attributes of cucumber fruit. Higher EC levels were found to lower the TSS, pH, and osmolality of the fruit, resulting in inferior quality that is not suitable for commercial purposes. Additionally, an increase in fruit juice acidity was found to lower the alkalinity and antioxidant properties of cucumber, which is not ideal from a health perspective (Murad and Nyc, 2016). Therefore, maintaining an optimal electrical conductivity of 2.6 dS/m in the nutrient medium improves both the physiochemical properties and the average number of fruit sets per plant. Future research can explore the yield per plant and the essential nutrient content in the fruit to better understand the significance of optimal electrical conductivity in the nutrient medium.

5. Conclusion

Optimizing growth conditions, ensuring high yield, and meeting quality standards in commercial production of hydroponically grown cucumber plants require precise and balanced EC in the nutrient medium. While morphological attributes are more dependent on the genotype of the cultivated variety, physiochemical parameters such as TSS, pH, and osmolality are more dependent on the electrical conductivity of the nutrient medium. Although the average number of fruits per plant was identical for the low EC level, treatment T2 (2.6 dS/m) resulted in optimal levels of TSS, pH, and osmolality of fruit juice for commercial production of cucumber. Therefore, a 2.6 EC level is recommended for superior quality of hydroponically grown cucumber under a high-tech greenhouse production system.

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Poudel; Software: Samir Shrestha, Pankaj Kumar Yadav, Bishal Khadka; Supervision: Bishal Khadka, Laxman Poudel; Validation: Bishal Khadka; Visualization: Samir Shrestha, Pankaj Kumar Yadav, Bishal Khadka; Writing – original draft: Samir Shrestha, Pankaj Kumar Yadav, Bishal Khadka, Laxman Poudel; Writing – review & editing: Samir Shrestha, Pankaj Kumar Yadav, Bishal Khadka, Laxman Poudel, Ashok Joshi. All authors have read and agreed to the published version of the manuscript.

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