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Evaluation of the response of some lettuce cultivars to growth, production, and quality indicators using hydroponic systems

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NFT; DWC; DST; Carotenoides; Romaine and Iceberg lettuce cultivars; Hydroponics.

The research was conducted at Abi Jarsh Farm in the Faculty of Agricultural Engineering at Damascus University during the first season of 2020-2021 and the second season (experimental repetition) of 2021-2022. The experiment aimed to study the evaluation of growth, production, and quality indicators for two lettuce varieties, Romaine and Iceberg, within various hydroponic techniques: Nutrient Film Technique (NFT), Drip System Technique (DST), Deep Water Culture (DWC), and using three different concentrations of nutrient solutions (100%, 50%, 25%). The results of the analysis of variance, according to chemical analyses, showed that the average of the Romaine variety had the highest percentage in the Carotenoids pigment estimation index for lettuce leaves compared to the Iceberg variety. Additionally, the Romaine variety recorded the highest percentage in the Total Soluble Solids (TSS%) estimation index for lettuce leaves compared to the Iceberg variety. Meanwhile, the results of the variance analysis, according to physical tests, indicated that the average of the Iceberg variety had the highest percentage in the number of leaves compared to Romaine, while the Romaine variety recorded the highest value in the indicator of the total green length and inner stem.

1. Introduction

Lettuce is a widely distributed leafy green globally, holding importance comparable to major vegetable crops such as tomatoes, cucumbers, and cabbage. Belonging to the Asteraceae or Compositae family, lettuce is an herbaceous plant. Romaine lettuce cultivation thrives in moderately cold climates and has spread from Egypt to Greek lands through trade (Bouras, 2004). Humans have historically relied on agriculture, deriving their primary food source from it. With increasing living standards, it has become imperative to develop means of obtaining daily sustenance and improving agricultural methods. Primitive or traditional methods have become inefficient in the face of growing food demand, given their reliance on rainfall conditions and weather predictions, limiting year-round productivity.

However, scientific advancements have enabled humans to understand plant seasonality and their requirements for factors such as moisture and sunlight. This understanding has led to the creation of artificial environments, facilitating the cultivation of summer and winter vegetables (leafy and fruity) outside their natural seasons. Scientific progress in agriculture has reached modern techniques and technology, including hydroponics (water-based cultivation) introduced by Johnson and colleagues in 2010.

A field experiment conducted by Mabkbb and Du Ploy (2009) compared field and hydroponic cultivation of lettuce. The study revealed that hydroponically grown plants exhibited faster development, better plant height, and an increase in the total soluble solids percentage in the leaves compared to field cultivation. Bisignano et al. (2002) observed increased productivity and total soluble solids when using the thin nutrient film technique and the immersion technique with stabilizing gravel for lettuce cultivation, as opposed to traditional farming methods.

Ghahsare et al. (2010) investigated the impact of hydroponic farming techniques on the growth and absorption of certain elements in lettuce. Significant differences were found between treatments compared to traditional farming, both in terms of productivity and the concentration of elements in the leaves, such as nitrogen, phosphorus, and potassium.

In hydroponic farming, the required fertilizers for lettuce from seeding to harvest, measured in parts per million (ppm), are approximately as follows: nitrogen: 140, potassium: 96, phosphorus: 25, magnesium: 25, calcium: 150, sulfur: 33, iron: 2.5, manganese: 1.0, zinc: 0.06, boron: 0.450, copper: 0.05, and molybdenum: 0.05 (Publications of the UAE Ministry of Environment and Water, 2013)

2. Materials and Methods

2.1 Research Setting

The study was conducted at the Faculty of Agricultural Engineering, Damascus University, in the Horticulture Department at the Research Laboratory for Hydroponics and Physiology (for conducting physical tests) and the Research Laboratories of the Biotechnology Department (for conducting chemical analyses).

2.2. Studied Plant Material

The study was conducted on two varieties of lettuce: Romaine, a local variety, and Iceberg, a European variety. Both are considered sought-after varieties in our country and are widely used in the commercial sector, particularly in restaurants and tourist resorts. They meet industrial standards, are resistant to diseases and pests, and have good storage capability for an extended period. Additionally, they contain a high percentage of water and mineral elements such as nitrogen, phosphorus, potassium, and magnesium. These varieties are known for their colour, taste, and nutritional value compared to other varieties, making them available to consumers for extended periods. It's worth mentioning that their importance is also dependent on individual preferences and nutritional needs.

Romaine Lettuce: Originating from Egypt and widespread in the Levant, the Mediterranean, and the Arab world. It has a vertical, elongated head with a dark green colour. The plant can grow vertically, reaching a length of more than 25 cm, and the root system may extend to more than 20 cm (Al-Basit, 2003).

Iceberg Lettuce: Originating from Europe, it has a round, spherical shape with a light green colour. The plant can reach a length of more than 20 cm, and the root system may extend to more than 15 cm (Al-Basit, 2003).

2.3. Seedling Production

The lettuce seeds were planted in germination trays in mid-September using only peat within a transparent plastic greenhouse with a temperature of 23 degrees Celsius. This greenhouse serves as a protected environment covered with transparent plastic to shield against external conditions, ensuring heat retention and providing lighting within the chambers. The greenhouse is equipped with ventilation, cooling, heating, and night time lighting technologies, allowing control over the room temperature. After 15 days, the seeds sprouted, and watering was done with regular water only.

After 45-50 days from planting, the seedlings were transferred to a hydroponic system in late October. In November and December, the plants were nurtured using nutrient solutions with carefully controlled concentrations. The plants were harvested at the stage of maturity, with the formation of solid heads, in January before the appearance of shoots, floral growth, and the elongation of the inner stem. The selection of suitable seedlings was based on the size of the first true leaf, with at least 80% of the seedlings exhibiting typical and simple growth patterns.

The chosen typical seedlings were transferred to hy-

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droponic farming systems exposed to natural sunlight throughout the day in an outdoor environment, without the use of artificial lighting.

2.3.1. Reasons for choosing Hoagland and Cooper solutions with specified ratios and concentrations

Hoagland and Cooper's solution is a nutrient solution used in hydroponics to provide essential nutrients needed for plant growth and development. This solution was developed by agricultural scientists Dennis Hoagland and Wilbur Cooper and has become widely recognized and utilized in the field of research and hydroponic agriculture.

The Hoagland and Cooper's solution contains a complete set of essential nutrients required for plant growth, including nitrogen, phosphorus, and potassium, along with secondary nutrients and trace elements.

Control of Nutrient Composition: The nutrient solution composition can be adjusted according to the plant's needs and various growth stages, allowing for optimal nutrient balance.

Ease of Use: Hoagland and Cooper solution is easy to use, as it can be prepared easily as needed and utilized in water irrigation systems.

Application in Scientific Experiments: This solution is used in scientific experiments and agricultural research to assess the effects of different nutrients on plant growth and performance.

Control of Environmental Conditions: It aids in precise adjustment and monitoring of growth conditions, including water and nutrient composition, improving the quality and efficiency of nutrient supply to plants.

Application in Hydroponic Systems: Hoagland and Cooper's solution is suitable for use in hydroponic systems such as NFT, DWC, and DST. It can be easily added to irrigation water in these systems, enhancing water and fertilizer use efficiency and increasing productivity per unit area compared to other hydroponic systems.

Achieving Balanced Growth: Contributes to achieving balanced growth for plants and the proper development of all plant parts.

Hoagland and Cooper's solution is a crucial tool in plant cultivation in aquatic environments, allowing farmers and researchers to achieve accurate results and effective control over plant growth conditions.

It is noted that Hoagland solution contains a significant amount of nitrogen and potassium, making it highly suitable for plant development. It is particularly good for leafy vegetables, especially lettuce, which requires lower nutrient concentrations, achieving the study's economic feasibility with varying concentrations of nutrient solutions based on the required salt weights derived from the Hoagland table.

2.3.2. Control or Monitoring to Ensure Uniform Conditions in All Experimental Transactions

The experiment was conducted within a hydroponic system comprising various hydroponic farming techniques. These techniques operate simultaneously to carry out the experiment, interconnected through accessories, PE agricultural irrigation pipes, and PVC pipes. Additionally, a shared tank for the techniques, filled with the nutrient solution, is present. When the nutrient solution level decreases in the basin, it is adjusted and replenished based on changes in acidity, the number of absorbed elements by the plant, and the balance between cations and anions in the solution.

If the plant's absorption of anions is greater than cations, it leads to an increase in pH value, making the solution alkaline (Marschner, 1995). This is adjusted by adding certain modified chemical compounds to regulate acidity, such as adding acids to reduce alkalinity, like nitric acid, phosphoric acid, or sulphuric acid (De Rijck and Schrevens, 1997).

Electrical conductivity is an indirect method for measuring the osmotic solution voltage of the nutrient solution. It is an indicator of the concentration of dissolved salts in solutions, providing valuable information on the ions available to the plant in the root zone (Nemali and Van Iersel, 2004).

Studies indicate that each crop has an ideal electrical conductivity, significantly dependent on environmental factors (Sonneveld and Voogt, 2009). However, suitable values for the growth of most plants in soilless cultivation systems range between 1.5-2.5 ds/m. For lettuce, the pH tolerance for the nutrient solution is 5.6-6, and the salinity tolerance (electrical conductivity of the nutrient solution) is 1150-1250 microsiemens/cm Eljouk, Ali (2005).

2.3.3. Potential Constraints of Hydroponic Farming Methods and Techniques

Water Pollution: The use of nutrients and chemicals may lead to water pollution, especially if the concentrations of these substances are not properly controlled. Good control and water management practices are required to avoid this issue.

Infrastructure Cost: Establishing and maintaining infrastructure for hydroponic systems can be costly, especially when employing advanced techniques such as NFT or DWC.

Environmental Control: Managing environmental conditions, such as temperature, humidity, and light levels, can be challenging in hydroponic systems and may require advanced technology for effective control.

Disease and Pest Control: While hydroponic farming can reduce the spread of plant diseases, it may still be susceptible to pests and bacteria that can affect plants.

Variability in Crop Quality: Farmers may face challenges in achieving uniform crop quality in hydroponic environments, especially with variations in nutrient solution concentrations and environmental conditions.

Energy Consumption: Some hydroponic systems may require significant amounts of energy, especially when using artificial lighting to enhance plant growth.

2.4. Nutrient Solutions for Hydroponic Farming

These are solutions containing the necessary nutrients for plant growth, used in irrigating plants in soilless farming systems. Nutrient solutions consist of two sources of salts: dissolved fertilizers and salts present in the water. The nutrient solution must contain all the essential nutrients at appropriate concentrations for plant growth. Examples of solutions used to nourish leafy vegetables in soilless farming systems include:

1-3-2-Preparation Factors and Concentrations of the Nutrient Stock Solution for Hydroponic Farming. A study conducted by Bridgewood (2012) recommends the mixing of the nutrient solution to obtain a ready-to-use solution by diluting the concentrated stock solutions A and B by 100 times. This means adding 1 litre of each concentrated solution (A, B) to 98 litres of water separately to avoid the precipitation of mineral salts. It should be noted that the Hoagland solution has a high amount of nitrogen and potassium, making it suitable for plant development, especially for leafy vegetables that require lower nutrient levels when reducing the concentration to half or a quarter of the original concentration. Therefore, the study was conducted on three different concentration ratios of the nutrient solution, based on the weights of the required salts taken from the Hoagland table to prepare 1000 litres of this solution as follows:

2.4.1. First Concentration: Stock Solution (x1)

Solution A1: Contains calcium nitrate 656.40g and iron chelates 5.30g. Calcium nitrate is dissolved in 10 litres of water until completely dissolved, then iron chelates are dissolved in the same solution (Hogland and Arnon, 1950).

Solution B1: Contains monopotassium phosphate 115.03g, potassium nitrate 606.60g, magnesium sulphate 240.76g, manganese chloride 1.81g, copper sulphate 0.08g, boric acid 1.70g, ammonium molybdate 0.016g, zinc sulphate 0.22g. The first chemical is dissolved in 10 litres of water, and then the other substances are added until completely dissolved in the same solution (Hogland and Arnon, 1950).

2.4.2. Second Concentration: Stock Solution (x2)

Solution A2 and B2 are prepared using the same method as described above, with the mineral elements dissolved in 12.5 litres of water until completely dissolved.

2.4.3. Third Concentration: Stock Solution (x3)

Solution A3 and B3 are prepared using the same meth-

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Table 1. Hoagland Solution (Hogland - Arnon 1950)

Element	Concentration (ppm)
Nitrogen (N)	210
Phosphorus (P)	31
Potassium (K)	235
Calcium (Ca)	200
Magnesium (Mg)	48
Iron (Fe)	1-5
Manganese (Mn)	0.5
Copper (Cu)	0.02
Zinc (Zn)	0.05
Boron (B)	0.5
Molybdenum (Mo)	0.01
Sulfur (S)	64

Table 2. Cooper Solution (cooper, 1988)

Element	Concentration (ppm)
Nitrogen (N)	200
Phosphorus (P)	60
Potassium (K)	300
Calcium (Ca)	170
Magnesium (Mg)	50
Iron (Fe)	12
Manganese (Mn)	2
Copper (Cu)	0.1
Zinc (Zn)	0.1
Boron (B)	0.3
Molybdenum (Mo)	0.2
Sulfur (S)	69

od as described above, with the mineral elements dissolved in 15 litres of water until completely dissolved.

2.5. Factors and Techniques of Hydroponic Agriculture

2.5.1. Nutrient Film Technique (NFT)

This technique relies on a thin nutrient film (nutrient solution) flowing in batches.

The film submerges the roots by 2-3 cm while the rest remains suspended in the air above the nutrient solution. This allows the roots to absorb oxygen and nutrients consecutively. When the nutrient solution circulates and returns to the tank, it becomes saturated with oxygen. PVC pipes with a length of not less than 1.5 m * 4 pipes are designed for this technique. The diameter of the pipes used is approximately 10 cm (4 inches), with circular holes drilled in one direction, reaching up to 28 holes. Seedlings are placed in these holes, and secured with plastic cups designed for hydroponics.

These cups have multiple holes for root emergence and water entry. The cups are filled with coarse agricultural media (vermiculite) for stability and support, and to prevent light penetration and evaporation. The tubes are painted white to reduce the temperature of the nutrient solution, especially in open and hot areas. The spacing between plants on the hydroponic tubes is 25 cm. One end of the tube is sealed, while the other end remains open, connected to other tubes using connectors and irrigation network accessories. Water levels in the channels are controlled by a valve that can be opened or closed as needed. Continuous pumping is used for irrigation, ensuring the nutrient solution flows to the upper end of each channel and gravitates down to wet the roots. (Dinda, 2011).

2.5.2. Deep Water Culture (DWC)

This method involves submerging and immersing the roots completely in a static nutrient solution. A plastic basin with dimensions of 1m * 1m * 0.25m is used. A perforated foam board is placed above the basin to prevent light penetration, and it serves to anchor the plants in plastic cups with holes, ensuring the roots remain in the nutrient solution. The cups are filled with coarse media (vermiculite), and a quarter of the container is filled with the nutrient solution. When the solution level drops, it needs to be refilled periodically, at least once a month, using a water pump. The number of plants corresponds to the number of holes, which can reach up to 25 plants. An air pump inside the basin provides necessary oxygen to the roots, and a drain plug allows for nutrient solution drainage as needed. (Alder et al., 2007)

2.5.3. Drip System Technique (DST)

This technique involves watering plants with a nutrient solution through a drip irrigation network equipped with thin spaghetti tubes and drainage points on PVC hydroponic pipes. The specifications for these pipes are similar to the NFT technique, but a pump is added to push the irrigation water from the nutrient solution tank to the PVC pipes. Additionally, an air pump is present in the irrigation or nutrient solution tank. A timer is used to determine the periods of drip irrigation, requiring 3-4 times a day for 20 minutes each. A support medium (vermiculite) is added for plant support and stabilization. (Newton and Jimmy, 2013).

2.6. Experimental Design

The experimental design relies on an integrated hydroponic agriculture system composed of various hydroponic techniques (NFT, DST, DWC) connected and interlinked through irrigation accessories, PE agricultural irrigation pipes, and PVC pipes. This system includes a shared tank at the base of the setup, connected to each hydroponic technique. The shared tank contains the nutrient solution and is equipped with both an air pump and a water pump. These pumps operate simultaneously to pump the nutrient solution and oxygen, delivering them to all three hydroponic techniques at the same time. The solution is then circulated back to the shared tank for recirculation. This closed-loop cycle can be interrupted by draining the nutrient solution from all connected pipes and the shared tank using a valve.

Additionally, the hydroponic system is equipped with a timer connected to the tank and the pump. When the system is activated, it operates all three techniques simultaneously within a single closed-loop circuit. The system utilizes one of the specified concentration ratios for the nutrient solution (100%, 50%, or 25%) and one of the two lettuce varieties (Romaine or Iceberg).

This experimental setup allows for multiple experiments, incorporating various techniques and parameters within the hydroponic agriculture system simultaneously. The use of different concentrations and lettuce varieties provides a comprehensive approach to studying the impact of these factors on plant growth and yield.

2.7. Experimental Setup

The experimental design includes a total of 18 trials, each combining different hydroponic techniques, nutrient solution concentrations, and lettuce varieties. Here is the breakdown of the experiments:

T1: NFT + Stock Solution (X1) + Romaine lettuce
T2: DST + Stock Solution (X1) + Romaine lettuce
T3: DWC + Stock Solution (X1) + Romaine lettuce
T4: NFT + Stock Solution (X2) + Iceberg lettuce
T5: DST + Stock Solution (X2) + Iceberg lettuce
T6: DWC + Stock Solution (X2) + Iceberg lettuce
T7: NFT + Stock Solution (X3) + Romaine lettuce
T8: DST + Stock Solution (X3) + Romaine lettuce
T9: DWC + Stock Solution (X3) + Romaine lettuce
T10: NFT + Stock Solution (X1) + Iceberg lettuce

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T11: DST + Stock Solution (X1) + Iceberg lettuce
T12: DWC + Stock Solution (X1) + Iceberg lettuce
T13: NFT + Stock Solution (X3) + Romaine lettuce
T14: DST + Stock Solution (X3) + Romaine lettuce
T15: DWC + Stock Solution (X3) + Romaine lettuce
T16: NFT + Stock Solution (X3) + Romaine lettuce
T17: DST + STOCK SOLUTION (X3) + Romaine lettuce
T18: DWC + STOCK SOLUTION (X3) + Romaine lettuce

2.8. Evaluated Indicators

2.8.1. Physical Tests

2.8.1.1. Leaf Area

• The leaf area of a fully grown leaf (cm2/leaf) was measured.
• 4-5 fully grown peripheral leaves were randomly selected from each treatment.
• The leaf area was measured using a program integrated with a leaf area measurement device.
• Length, width, perimeter, and area readings were taken and processed using ViewSonic Image.
• Leaf area per leaf was calculated (cm2/leaf) (Arenas et al., 2002).

2.8.1.2. Average Number of Leaves per Plant (Leaf/Plant)

4-5 replicates from each treatment were taken, and the number of leaves was calculated.

The average number of leaves per plant was determined (Kleiber & Grajek, 2015).

2.8.1.3. Length of Vegetative Canopy (cm)

The length of the vegetative canopy was measured using a measuring ruler from the surface of the medium to the end of the growth.

The length of the head was measured by determining the distance between the farthest two points in the leaf bundle (Mabkbb & Du Plooy, 2009).

2.8.1.4. Rigidity (Degree of Compactness)

Theoretically determined by measuring the length of the internal stem due to the inverse relationship between the length of this stem and the rigidity of the head.

Rigidity depends on the length of the internal stem; the shorter it is, the greater the rigidity and durability.

The length of the internal stem is the part extending from the base of the head to the end of the terminal bud (Haupt, 1999).

2.8.1.5. Wet and Saturated Weight of Vegetative Canopy (g)

At the end of the experiment, several plants were uprooted from each treatment, and their roots were cleaned thoroughly.

The vegetative canopy was separated from the roots, and its weight was measured (Haddad & Aubeid, 2011).

Wet weight: A leaf from each plant (4-5 plants) was taken and measured using a sensitive scale.

Saturated wet weight: The weighed leaves were placed in a saturated humid environment (a plastic box containing dry paper was moistened with water, and cellophane was placed over the leaves).

The leaves were left for 48 hours in a humid environment, and then they were weighed to obtain the saturated wet weight (Haddad & Aubeid, 2011).

2.8.2. Chemical Tests

2.8.2.1. Estimation of Chlorophyll Pigments (a, b) and Carotenoids

Using a Spectrophotometer (Schwallier et al., 2005).

Acetone Solution Preparation: 20 mL distilled water was added to 80 mL acetone.

Sample Preparation: Two random plants were selected from each replicate, and leaves weighing 3 g were taken from each replicate.

Grinding Procedure: The weighed samples were individually placed in a mortar and ground into small pieces. Gradually, 6 - 4 mL of acetone (80%) was added while continuing to grind the plant tissue well, leaving it until the colour disappeared away from light.

Filtration: The solution was filtered carefully and collected in a flask, and then the grinding was repeated using 3 mL of acetone.

If residual tissue in the mortar contained chlorophyll, it was re-extracted as before using 3 mL of acetone (or the mortar was washed with 3 mL of acetone). The extract was transferred to a standard flask, resulting in a total of 12 mL of chlorophyll-containing plant tissue extract.

The extract was placed in the special tubes of the centrifuge for 20 minutes at 5 degrees Celsius and a speed of 6000 rpm. The optical density (O.D) reading for the extract was recorded using a spectrophotometer after placing it in the glass cells of the spectrophotometer.

The absorbance of the resulting light filter at wavelengths of 470, 646, and 663 nanometres was recorded using a spectrophotometer.

The amount of chlorophyll a and b (mg/100ml) in wet leaves was estimated according to the equations:

- Chlorophyll a (mg/100ml) = 12.21(A663) - 2.81(A646)

- Chlorophyll b (mg/100ml) = 20.13(A646) - 5.03(A663)

- Carotenoids (mg/100ml) = [1000 * A470 - 3.27 * 1.9 Chl a - 1.4 * Chl b] / 214 (Wittwer & Honma, 1976).

2.8.2.2. Total Soluble Solids (TSS%)

The percentage of total soluble solids in fruits was measured using a digital refractometer after taking a sample from the lettuce leaf juice and placing a drop of it in the device (Schwallier et al., 2005).

2.9. Statistical Analysis

The statistical analysis of the average of two agricultural years was conducted using a split-plot design within randomized sectors. The experiment data was appropriately tabulated and processed using the SPSS program to assess the impact of hydroponic farming techniques on the measured indicators of lettuce plant production and growth. The Least Significant Difference (LSD) was calculated at a 95% confidence level for comparing values using the Two-Way Analysis of Variance method.

3. Results

According to the physical tests, Tables (3,4,5) illustrate the measured indicators for the average of lettuce varieties (Romaine and Iceberg) used in hydroponic farming techniques and treated with three different concentrations of nutrient solution. A statistically significant superiority was observed in the average of the Iceberg variety in the indicator of the number of leaves, reaching a value of 44 leaves compared to the Romaine variety with a value of 32 leaves. The LSD value was <0.05, while no significant differences were recorded between the Iceberg and Romaine varieties in the leaf area indicator. The Romaine variety recorded an average of 292.9 cm^2, whereas the Iceberg variety recorded 238.8 cm^2. The LSD value was 0.05. Significant differences were also found in the indicator of saturated wet leaf weight in favor of the Romaine variety, recording a value of 25.5 g, while the Iceberg variety recorded a value of 20 g, where the LSD value was <0.05.

As for the indicator of the length of the total green mass, the Romaine variety showed a significant superiority with a value of 33.5 cm compared to the Iceberg variety with a value of 27.7 cm. The LSD value was <0.05. The Romaine variety also showed a significant advantage in the indicator of internal stem length compared to the Iceberg variety, with values of 8 and 4.9, respectively. The LSD value was <0.05.

According to the chemical analyses, Table (6,7) shows the studied indicators for the average of lettuce va-

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Table 3. Summary of the Physiological Indicators Studied in the Physical Tests for the Average of Lettuce Varieties (Romaine and Iceberg) Used in Hydroponic Farming Techniques and Treated with Three Different Concentrations of Nutrient Solution.

Plant leaves area				**Saturated wet weight of leaves**			
Second Category	**First Category**	**Concentration**	**Technique**	**Second Category**	**First Category**	**Concentration**	**Technique**
Iceberg	**Romaine**			**Iceberg**	**Romaine**		
310.5	**342.4**	**100%**	**NFT**	**24.73**	**28.25**	**100%**	**NFT**
250.23	**290.7**	**50%**		**21.7**	**27.07**	**50%**	
164	**236**	**25%**		**18.24**	**21.95**	**25%**	
Second Category	**First Category**	**Concentration**	**Technique**	**Second Category**	**First Category**	**Concentration**	**Technique**
Iceberg	**Romaine**			**Iceberg**	**Romaine**		
292.6	**325.6**	**100%**	**DST**	**16.32**	**27.66**	**100%**	**DST**
210.4	**240.3**	**50%**		**14.92**	**22.19**	**50%**	
122.8	**203.5**	**25%**		**12.45**	**20.11**	**25%**	
Second Category	**First Category**	**Concentration**	**Technique**	**Second Category**	**First Category**	**Concentration**	**Technique**
Iceberg	**Romaine**			**Iceberg**	**Romaine**		
322.31	**418.75**	**100%**	**DWC**	**26.81**	**31.88**	**100%**	**DWC**
286.7	**303.9**	**50%**		**24.13**	**27.39**	**50%**	
189.75	**275.31**	**25%**		**20.43**	**23.07**	**25%**	
238.8 a	**292.9 a**	**Average category**		**20b**	**25.5 a**	**Average category**	
0.1096		**LSD 5%**		**0.0162**		**LSD %5**	

The different letters within the same row indicate significant differences at (LSD 0.05), and the alphabetical order denotes the significance of differences between treatments.

Table 4. Summary of the Physiological Indicators Studied in the Physical Tests for the Average of Lettuce Varieties (Romaine and Iceberg) Used in Hydroponic Farming Techniques and Treated with Three Different Concentrations of Nutrient Solution.

Total Length Of Leaves				**Inner Leg Length**			
Second Category	First Category	Concentration	Technique	Second Category	First Category	Concentration	Technique
Iceberg	**Romaine**			**Iceberg**	**Romaine**		
30	37.1	100%	NFT	4	5.8	100%	NFT
28.2	33.5	50%		4.9	7.1	50%	
25.1	30	25%		5.8	11.4	25%	
Second Category	First Category	Concentration	Technique	Second Category	First Category	Concentration	Technique
Iceberg	**Romaine**			**Iceberg**	**Romaine**		
29.3	36.2	100%	DST	4.3	6.5	100%	DST
26.7	32	50%		5.2	8.2	50%	
22	28.2	25%		6.3	12	25%	
Second Category	First Category	Concentration	Technique	Second Category	First Category	Concentration	Technique
Iceberg	**Romaine**			**Iceberg**	**Romaine**		
31.6	38.7	100%	DWC	3.5	5	100%	DWC
29	35.4	50%		4.7	6.7	50%	
27.8	30.8	25%		5.5	9.3	25%	
27.7**b**	33.5**a**	Average Category		4.9**b**	8**a**	Average Category	
0.0015		**LSD 5%**		0.0026		**LSD 5%**	

The different letters within the same row indicate significant differences at (LSD 0.05), and the alphabetical order denotes the significance of differences between treatments.

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Table 5. Summary of the Physiological Indicators Studied in the Physical Tests for the Average of Lettuce Varieties (Romaine and Iceberg) Used in Hydroponic Farming Techniques and Treated with Three Different Concentrations of Nutrient Solution.

Number Of Plant Leaves			
Second Category	First Category		
Iceberg	Romaine	Concentration	Technique
50	37	100 %	NFT
44	32	50%	
37	27	25%	
Second Category	First Category		
Iceberg	Romaine	Concentration	Technique
47	32	100%	DST
41	29	50%	
35	26	25%	
Second Category	First Category		
Iceberg	Romaine	Concentration	Technique
53	40	100%	DWC
49	35	50%	
40	30	25%	
44a	32b	Average Category	
0.0003		LSD 5%	

Note: The different letters within the same row indicate significant differences at (LSD 0.05), and the alphabetical order denotes the significance of differences between treatments

rieties (Romaine and Iceberg) used in hydroponic farming techniques and treated with three different concentrations of the nutrient solution. Most of the studied indicators indicated that the average of the Romaine variety recorded higher values in the studied indicators. According to the estimation of chlorophyll A, there were no significant differences for the averages of the Romaine and Iceberg lettuce varieties, each recording values of 15.81 and 9.93, respectively.

It's worth noting that the LSD value is greater than 0.05. Additionally, there were no significant differences in the chlorophyll B indicator for the averages of the Romaine and Iceberg lettuce varieties, with each recording values of 9.25 and 6.98, respectively, and LSD>0.05. As for the indicator studied in estimating carotenoid pigments, the Romaine lettuce variety showed a significant superiority over the Iceberg lettuce variety, with values of 6.18 and 5.24, respectively. Notably, LSD<0.05. Regarding the studied indicators in estimating the total soluble solids percentage, there were significant differences in favor of the Romaine lettuce variety, reaching a percentage of 12.16, compared to the Iceberg lettuce variety, which reached a percentage of 5.27. It's important to mention that LSD<0.05.

Table 6. The studied indicators in the chemical analyses for the average of lettuce varieties (Romaine and Iceberg) used in hydroponic farming techniques and treated with three different concentrations of the nutrient solution.

Carotene Pigment			
Second Category	First Category	Concentration	Technique
Iceberg	**Romaine**		
5.64	6.22	**100%**	NFT
5.52	6.14	**50%**	
5.2	6.03	**25%**	
Second Category	First Category	Concentration	Technique
Iceberg	**Romaine**		
5.27	6.19	**100%**	DST
4.99	5.85	**50%**	
3.97	5.26	**25%**	
Second Category	First Category	Concentration	Technique
Iceberg	**Romaine**		
5.66	6.73	**100%**	DWC
5.56	6.67	**50%**	
5.34	6.54	**25%**	
5.24 **b**	6.18 **a**	Average Category	
0.0009		**LSD 5%**	

Percentage Of Total Dissolved Solids			
Second Category	First Category	Concentration	Technique
Iceberg	**Romaine**		
7.6	14.4	**100%**	NFT
5.4	13	**50%**	
3.2	11.2	**25%**	
Second Category	First Category	Concentration	Technique
Iceberg	**Romaine**		
5	10.6	**100%**	DST
4.6	9	**50%**	
3	7.2	**25%**	
Second Category	First Category	Concentration	Technique
Iceberg	**Romaine**		
8.4	16	**100%**	DWC
6.2	15.2	**50%**	
4	12.8	**25%**	
5.27 **b**	12.16 **a**	Average Category	
<.0001		**LSD 5%**	

Note: The different letters within the same row indicate significant differences at (LSD 0.05), and the alphabetical order denotes the significance of differences between

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Table 7. The studied indicators in the chemical analyses for the average of lettuce varieties (Romaine and Iceberg) used in hydroponic farming techniques and treated with three different concentrations of the nutrient solution.

Chlorophyll A Pigment				**Chlorophyll B Pigment**			
Second Category	First Category	Concentration	Technique	Second Category	First Category	Concentration	Technique
Iceberg	**Romaine**			**Iceberg**	**Romaine**		
10.08	14.23	**100%**	NFT	6.4	10.38	**100%**	NFT
9.88	13.84	**50%**		6.03	9.93	**50%**	
9.26	12.59	**25%**		5.58	9.51	**25%**	
Second Category	First Category	Concentration	Technique	Second Category	First Category	Concentration	Technique
Iceberg	**Romaine**			**Iceberg**	**Romaine**		
7.32	13.73	**100%**	DST	5.85	5.4	**100%**	DST
7.04	13.08	**50%**		5.12	4.97	**50%**	
6.5	12.47	**25%**		4.96	4.57	**25%**	
Second Category	First Category	Concentration	Technique	Second Category	First Category	Concentration	Technique
Iceberg	**Romaine**			**Iceberg**	**Romaine**		
13.636	25.58	**100%**	DWC	10.1	13.26	**100%**	DWC
13.26	24.08	**50%**		9.95	13.1	**50%**	
12.47	12.71	**25%**		8.85	12.17	**25%**	
9.93**a**	15.81**a**	Average Category		6.98**a**	9.25**a**	Average Category	
0.7578		**LSD 5%**		0.1107		**LSD 5%**	

Note: The different letters within the same row indicate significant differences at (LSD 0.05), and the alphabetical order denotes the significance of differences between treatments

4. Discussion

The experiments involving the use of lettuce varieties (Romaine and Iceberg) in hydroponic farming techniques, treated with three different concentrations of the nutrient solution, generally showed a positive impact on the physical and chemical characteristics of the used varieties. Hydroponic farming techniques, including DWC, NFT, and DST, played a significant role in influencing the growth, production, and quality standards of lettuce varieties. Additionally, the use of different concentrations of the nutrient solution contributed to the improvement of physical traits, such as shoot length, saturated leaf wet weight, internal stem length, leaf count, and leaf area.
The Romaine lettuce variety exhibited higher values in most of the studied indicators, and this can be directly attributed to the larger and longer roots of the Romaine variety compared to Iceberg. This led to increased water supply and nutrient elements, as studied by Dubik et al. (1990), promoting greater root system proliferation and enhanced absorption from the nutrient solution (water + mineral elements) in the root environment. The increased root mass, in turn, positively affected the number of absorbing root hairs, resulting in higher nutrient uptake.

The observed increase in leaf area is not always linearly associated with the leaf count due to genetic variation in the growth habits of varieties (longitudinal or horizontal leaf growth) and differences in growth factors during plant development, according to studies by Hall et al. (1988) and Haupt (1999). Growth regulators in the roots, such as cytokinins, stimulate hormones in the shoot to increase leaf count. Verdonk et al. (1982) and Albaho et al. (2009) confirmed that an increase in leaf area is not always directly correlated with leaf count due to genetic variability in growth habits and growth factors.

Regarding chemical analyses, the experimental results for the Romaine variety showed higher values in estimating carotenoid content, chlorophyll A and B, and the total soluble solids percentage in the leaves compared to the Iceberg variety. This can be attributed to the larger leaf area, leading to increased accumulation and concentration of essential nutrients, such as nitrogen, calcium, and magnesium. These nutrients are crucial for chlorophyll synthesis, protecting chlorophyll molecules from oxidation, and enhancing photosynthetic efficiency.

This study aligns with previous research by Bailey et al. (2010), which emphasized the positive impact of potassium accumulation in promoting enzymatic reactions, nutritional transformation, and increasing carbohydrate content in leaves.

In conclusion, the integration of hydroponic farming techniques and varying concentrations of nutrient solutions had a significant positive influence on the growth and chemical composition of lettuce varieties. The Romaine variety exhibited superior performance in several indicators, emphasizing the importance of considering both cultivation techniques and genetic variations when optimizing lettuce production in hydroponic systems. The results align with existing literature and provide valuable insights for enhancing lettuce cultivation practices for improved yield and quality.

Among the limitations faced by the study: The establishment cost of a hydroponic farming system may be higher than traditional farming systems, and the high humidity environment may contribute to the spread of diseases and pests, thus affecting research outcomes. Operating water pumps and systems can consume large amounts of energy, and in some regions, there may be a shortage of electrical energy, posing a barrier to achieving results. Regular monitoring is required to adjust the acidity, alkalinity, and electrical conductivity of the nutrient solution, as they affect the plant's ability to absorb mineral elements and can lead to salt deposition, thereby negatively impacting the study results.

Potential Effects on the Surrounding Environment:

1. The system may require large amounts of water.

2. The use of nutrients in water may lead to the leakage of nutrients and pollution of the surrounding water.

3. Operating pumps and systems consume large amounts of energy.

4. Regular water changes in the system can result in the production of used water.

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5. Changes in temperature or lighting structures may affect aquatic biological life.

6. Building hydroponic greenhouses and advanced systems may require significant construction resources.

7. Transitioning to hydroponic farming systems may impact employment opportunities in traditional agriculture.

5. Conclusions and Recommendations

1. The results demonstrated a significant impact of the Romaine lettuce variety compared to the Iceberg variety in the studied indicators, including shoot length, internal stem length, leaf count, saturated leaf wet weight, and utilized in hydroponic farming.

2. It is recommended to use different concentrations of the nutrient solution to cultivate various lettuce varieties within hydroponic farming techniques. This approach allows for optimizing the growth conditions based on the specific needs of each lettuce variety.

3. Further studies should explore the influence of different growth media available in our environment on the growth and production of various vegetables. Understanding the interaction between different growing environments and plant varieties can contribute to more sustainable and efficient agricultural practices.

4. The adoption of modern hydroponic farming techniques such as DWC, NFT, and DST is advised for cultivating different lettuce varieties in protected environments. These techniques can enhance overall growth, increase production, and improve the quality of the studied hybrids.

5. The results highlighted a significant impact of the Romaine lettuce variety compared to the Iceberg variety in the studied indicators, including the percentage of total soluble solids and carotenoids. This emphasizes the importance of selecting the appropriate lettuce variety based on the desired chemical composition and nutritional content.

6. In summary, the findings provide valuable insights into the optimal cultivation practices for lettuce varieties in hydroponic systems. The superiority of the Romaine lettuce variety in various indicators suggests its suitability for hydroponic farming, and the recommendations aim to guide future research and agricultural practices for enhanced vegetable production and quality.

Incorporating Suggestions

1. Selecting Suitable Plant Species: Identify plants that are suitable for local climatic conditions and have the ability to thrive in hydroponic systems.

2. Hydroponic Agriculture Technology: Choose the appropriate hydroponic technology for local conditions, such as NFT (Nutrient Film Technique), DWC (Deep Water Culture), or drip irrigation systems. Adjust plant nutrient levels and nutrient concentrations according to plant needs and environmental conditions.

3. Environmental Monitoring: Utilize environmental monitoring systems to measure factors such as temperature, light availability, and humidity. In hydroponic systems, smart sensors and automatic irrigation systems can be employed to control environmental conditions.

4. Environmental Control Technology: In outdoor environments, use plastic greenhouses to provide additional protection and control over surrounding conditions.

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