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Advance an Automated Indoor Hydroponic Unit for Plant Growth Detection with Compatible for Two Different Plant Varieties

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ABSTRACT

The study aimed to design and fabricate an automated indoor hydroponic plant growth chamber, by comparing the manual system to determine plant growth and development and the sub-objective was to send data to the IoT platform. The sensor-based automated system incorporated pH, TDS, temperature, and humidity sensors, controlled by solenoid valves using Arduino. Tomato and lettuce plants were grown in both systems and growth parameters were measured. The results showed that the automated system maintained consistent temperature, humidity, pH, and EC levels similar to the outdoor system (vary in 30-32, 52-79, 5.5-6.5, and 1.5-2.5 dS/m ranges respectively). Furthermore, the automated indoor system significantly enhanced the plant growth of tomato and lettuce plants compared to the manual system. Significantly higher plant heights of 27.9±1.9 cm and 27.4±4.9 cm, the leaf lengths of 3.2±0.1 cm and 3.9±0.1 cm were observed for the tomatoes and the lettuces respectively in the automated indoor system. A significant difference was observed between the SPAD reading of the automated indoor tomato of 30±0.9 and the outdoor tomato of 26±0.4. Similarly, SPAD readings for the automated indoor lettuce of 23±0.3 and outdoor lettuce of 17±0.5 were significantly different ($Pr=<0.0001$, $Pr\leq 0.05$). These findings highlight the effectiveness of the automated hydroponic system in accommodating plant preferences and its potential for improving agricultural practices. By integrating IoT platforms for data analysis, this technology can optimize plant growth, enhance yields, and facilitate informed decision-making in hydroponic farming.

INTRODUCTION

Sri Lanka is a tropical agricultural country, that is frequently affected by which is frequently affected by sudden damages in agricultural production due to drastic climatic disasters like droughts, floods, and landslides (Weerasekara et al., 2021). The present economic crisis in Sri Lanka has exacerbated the country's agricultural production. The prime goal of farmers is to produce an adequate nutritious food supplement to feed the world's expanding population, eradicated food scarcity, and improve food security (Ginigaddara, 2020). There are different farming practices are practiced in various parts of the world based on a variety of variables such as plant variety, climate, water, and soil conditions. The type of farming is determined by some factors (Stringer et al., 2020). Farmers must identify the particular farming practices that are compatible with the local physical environment. They must also guarantee that their goods will be purchased in the neighborhood market. The sort of farming in question is determined by particular agricultural practices and the products that are produced (Balmford et al., 2012).

In 1925, greenhouses were established and the trend has initiated to grow plants in the plant houses with considering the disadvantages of traditional farming. Due to the rapid growth of the population, traditional farming methods could not afford to supply adequate food production for the rising demand (Fussy & Papenbrock, 2022). Even though cultivation in greenhouses has advantages, the soil medium application has become a burden due to the difficulty in conducting frequent management practices. As a result, hydroponic farming has been introduced and identified as a new alternative for the soil medium application that has many advantages and has later become the best form of indoor farming type.

Currently, Sri Lanka has made significant advancements in hydroponic farming and has effectively applied it to a variety of small-scale and large-scale agricultural output. Initially, only cultivation in nutrient fluids was referred to as hydroponics. Later cultivation in nutrient solutions as well as in other non-soil mediums became known as hydroponics cultivation. Today, all cultivations with or without soil, with or without other mediums, with the help of nutrient fluids, are known as irrigated/non-irrigated cultivations (Mazoyer & Roudart, 2006).

Urbanization and the current drawbacks in the food supply chain have brought new insight into the popularization of home gardening, urban gardening, and indoor farming in Sri Lanka. Urban home gardens usually possess limited space to cultivate. Where indoor farming, vertical farming, and hydroponics become fruitful solutions for modern world people (Kulathunga et al., 2022). Indoor farming has become the future of agriculture, as it needs limited spaces, and can grow using smart chambers, which could be automated and monitor the plant growth by providing all the required nutrients for healthy growth (Woodard, 2019).

Indoor plant technology refers to hydroponics or aquaponics which translates as soilless gardening. It can be performed both indoors and outdoors and using high-end or low-profile technology (Dholwani et al., 2018). Hydroponics is a form of gardening that usually uses no soil but instead grows plants in a solution of water and nutrients. “Albert solution” is the most commonly used nutrient solution used for hydroponics in Sri Lanka. Faster and year-round plant and food growth are possible with a hydroponic system. Wick system, Deep Water Culture (DWC), EBB and Flow (Flood & Drain) system, Drip (recovery or non-recovery) system, Nutrient Film Technique (NFT), Aeroponics, and Aquaponics could be identified as the different types of modern advanced hydroponic systems (Alexander, 2000).

The ability to control optimum environmental conditions according to considered facts is one of the major advantages of automated systems. Conventional farming methods require a large amount of water for irrigation as they require large open spaces. But in an indoor system, it can be farming using limited space and limited resources. They are fitted with LED grow lights so that they provide adequate light needed by plants. Now, there are a lot of indoor hydroponic systems developed with the technology (Rexford & Rexford, 1910).

Several plants can be grown this way such as lettuce, tomatoes, cucumbers, root vegetables, herbs, greens, and all kinds of flowering plants. Growing two different crop types which possess different environmental conditions and nutrient levels in one hydroponic system is a challenging fact. It is important to identify the optimum levels of the different crop types which are compatible with the efficient automated levels. To observe that, compare two systems by automatically controlling pH values and Electrical Conductivity (EC) in the indoor system and manually controlling the outdoor system. When water flows in the normal way it can affect the plants because pH and EC values change. But when it is automated pH and EC values are balanced automatically so it fluctuates in the optimum range and continuously provides a balanced nutrient solution. To observe the design of two hydroponic systems as indoor and outdoor systems and compare the results of both systems.

The main objectives of this research are to design and fabricate an automated indoor hydroponic plant growing chamber with compatible the different plant architectures of two plant varieties, to determine the efficiency of the system compared to the manual system, and to compare the plant growth and development. Sub-objective is to send data to the IoT platform (Thingspeak) for monitoring and analyzing purposes.

System designed to design and fabricate automated indoor hydroponic plant growth chamber, to determine effective system with comparing manual system and to determine plant growth and development. The automated system is a sensor-based system that uses a pH sensor, TDS sensor, and temperature and humidity sensor.

METHODS

The research was conducted in the Faculty of Technology premises in Kamburupitiya Matara, Sri Lanka. This research period started on September 2021 and ended on August 2022. Two hydroponic systems were designed as an automated indoor system and a manual outdoor system. Two pumps, piping and drainage connectors, two supporting frames (wood), and two water containers were used to make both systems. Twenty net cups, grow cubes (sponge), and plants were used to grow plants for each system and the Albert solution was applied as a nutrient solution. Apart from these materials, transparent casing, pH sensor, TDS sensor, DHT11 sensor, LED strips, pH controller, and EC controllers were incorporated in the indoor system. Furthermore used an Arduino UNO microcontroller board (based on the ATmega328P datasheet), four solenoid valves, a relay module, and a GSM module were included.

The automated system is a sensor-based system that uses a pH sensor, TDS sensor, and temperature and humidity sensor to determine the system. There were four solenoid valves to control pH and EC levels. The indoor case was made out of wood and was covered it using a polyethylene case. The frame that holds hydroponic channels, was also made by using wood. Before placing the channels in the frame, the hydroponic channels and frame were painted in white color. When making holes in channels used a 65 mm hole saw and made 5 holes in one channel. There was such kind of 4 channels in one system. There was a 1 ft distance between the first two channels and their placed lettuce plants. In other two channels have a 2 ft distance from each and placed tomato plants in those channels because of their height. According to the differences in the heights, it accommodates the plants with different architectures.

The controlling part of this system is done by using Arduino UNO (ATmega328P microcontroller). Temperature and humidity levels were measured in this automated system by using a DHT11 sensor. According to instructions, artificial sunlight was automatically turned on and off to maintain the required temperature of the system and provided the required amount of light for plant growth. LED strips were used to provide 10 hrs of light and 14 hrs of dark automatically. The sensors of the indoor automated system, other components' locations, and the plants were shown in Figure 1.

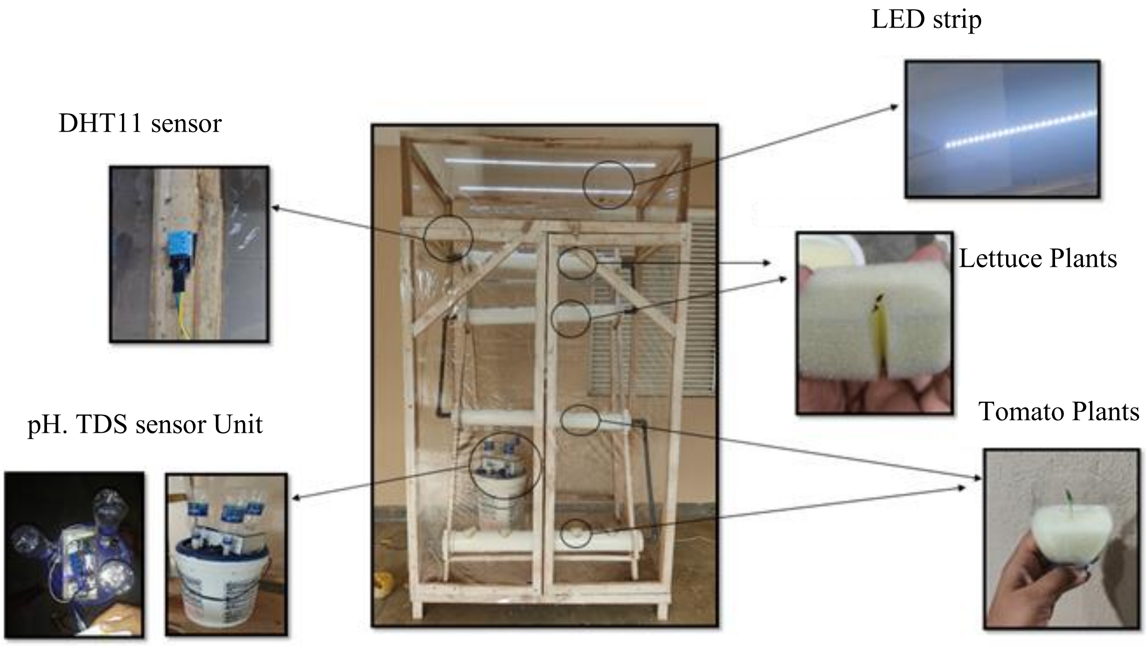


Figure 1. Sensor Placed Places

Albert's solution was used as the main nutrient in this system. Four solenoid valves were used to control the pH and EC levels of the system. The automated system was programmed to take the pH and EC values every 2 hrs. The solenoid valves were operated and released relevant solutions to maintain the required pH and EC levels in the nutrient solution. Calcium Hydroxide ($Ca(OH)_2$)

was used to increase the pH and Nitric Acid (HNO_3) was used to decrease the pH value.

To measure Electrical Conductivity can use an EC meter and an EC sensor were used instead TDS sensor used to measure EC value for this research. To calculate the EC value from the TDS sensor reading, equation 1 is used.

TDS (mg/L) = k × EC (μS/cm) (Rusydi, 2018) (1)

Lettuce (*Lactuca sativa*) and tomatoes (*Solanum lycopersicum*) were grown in CRD design in 10 replicates each for the indoor and outdoor systems. The plants were planted in coco-pellet medium and five seeds were placed in one plastic cup. Seed cups were kept in a dark area until they get germinated. Later, the plants were transplanted into single cups with coco pellet medium and placed them in the respective hydroponic systems. The optimum pH range of lettuce is 5.5 – 6.5 and the optimum pH range of tomatoes is 5.5 - 6.5. A balanced pH range of 5.5- 6.5 for both varieties was used for the particular experiment. The optimum EC value of Lettuce is 1.4 – 1.8 mS/cm and the optimum EC value of Tomatoes is 1.6 – 5.0 dS/m. A balanced EC range of 1.5 – 2.5 dS/m has been selected EC range for both varieties for the particular experiment. The nutrient solution in these two systems should be refreshed at least once every two weeks. All the management practices were conducted according to the hydroponic management guidelines of the Department of Agriculture in Sri Lanka. The data were collected once every two days' time from both systems. The quantitative variables of plant height, leaf number, leaf width, leaf length, SPAD reading, and lux meter readings were measured. The plant height and leaf size were measured by using a ruler. When measuring leaf size on tomato plants, always data were taken from the second leaf that is well above the plant. Weather data of the temperature and humidity were measured in every two days intervals separately using wet- and dry-bulb hygrometers.

Figure 2. (A) Indoor system (B) Outdoor system

Figure 2 represents a comparison between the indoor system and the outdoor system. The data was analyzed through the Analysis of Variance (ANOVA) test and the mean separation was conducted Duncan's Multiple Range Test (DMRT) by using SAS OnDemand for Academics statistical software (SAS, n.d.). The graphs were used to present the comparison between the weather conditions and the pH and EC levels in each system through the Microsoft Office 365 Excel software.

RESULTS AND DISCUSSION

Plants grown in an automated indoor hydroponic system with control measures showed a more productive response than the normal outdoor hydroponic system. The controlled environment, precise nutrient delivery, enhanced pest and disease control, and reduced manual labor contribute to the overall success and increased productivity of plants grown in the automated indoor hydroponic system. The plant absorbs light in the wavelength range of 400–700 nm, which is defined as photosynthetically active radiation (PAR). The light intensity, light quality, and light duration could critically affect plant growth and development. According to Ahmed et al., (2020), several studies observed the different light intensities provided by LEDs and different photoperiods could distinctively influence the growth rate and morphogenesis of lettuce and tomato plants. Hence, we have selected the 10 hrs of light and 14 hrs of dark period for experimental purposes.

The comparison between the tomato plants and lettuce plants considering Morphological differences in automated indoor systems and outdoor systems are shown in Figure 3 and Figure 4 respectively. Comparatively larger plants were observed in tomato plants and lettuce plants in the automated indoor system. According to the ANOVA statistical analysis along with the Duncan Multiple Range Test (DMRT) conducted through SAS statistical software, the plant growth parameters of plant height, leaf length, leaf width, leaf amount, SPAD meter reading, and the LUX meter reading were compared.

Figure 3. Morphological differences of tomato in a) Outdoor system b) Indoor system

Figure 4. Morphological differences of lettuce in a) Outdoor system b) Indoor system

Significantly higher plants heights of 27.9±1.9 cm and 27.4±4.9 cm were observed for the tomatoes and the lettuces respectively in the automated indoor system compared to the tomatoes and the lettuces of 17.3±0.8 cm and 8.7±2.1 cm respectively in the outdoor system ($Pr=0.0064$, $Pr \leq 0.05$) (Table 1. A).

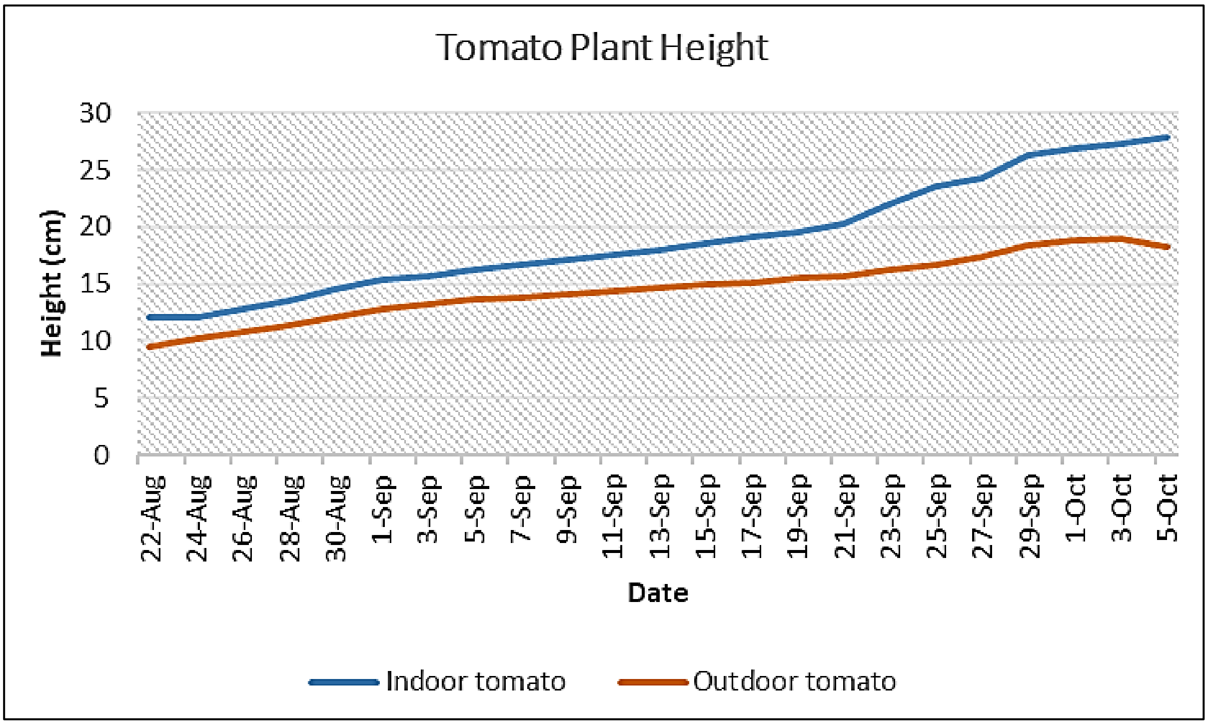
Table 1. A) Plant height, B) Leaf length, C) Leaf width, D) Leaf amount E) SPAD meter reading of the tomato and lettuce plants in an indoor automated system and the outdoor manual system

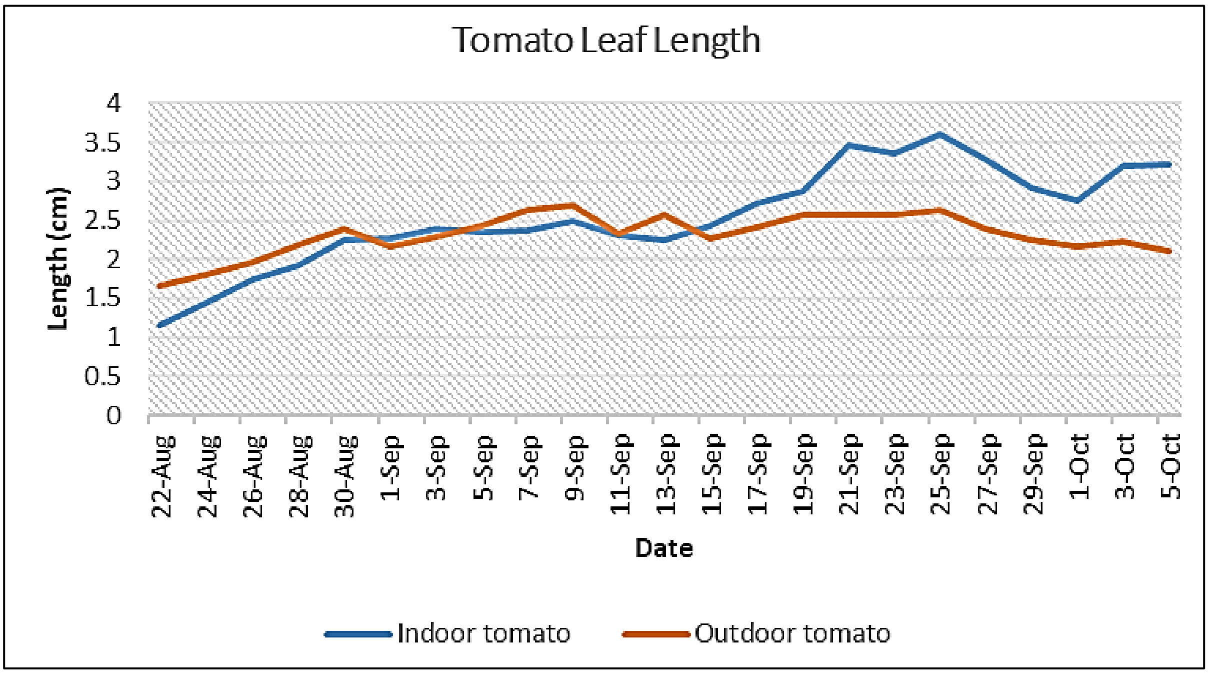
Plant growth parameter	Indoor system		Outdoor system	
	Tomato	Lettuce	Tomato	Lettuce
A) Plant height	27.89 ±1.91 a	27.38 ±4.85 a	17.31 ±0.76 ab	8.71 ±2.12 b
B) Leaf length	3.21 ±0.09 ab	3.94 ±0.16 a	2.18 ±1.57 b	2.86 ±0.17 a
C) Leaf width	1.14 ±0.03 a	0.33 ±0.03 b	0.33 ±0.03 a	0.31 ±0.02 b
D) Leaf amount	57.1 ±3.53 a	15.2 ±1.95 b	15.2 ±1.95 a	10.6 ±1.18 b
E) SPAD meter readings	30.08 ±0.96 a	26.17 ±1.31 a	26.17 ±1.31 b	16.51 ±1.57 b

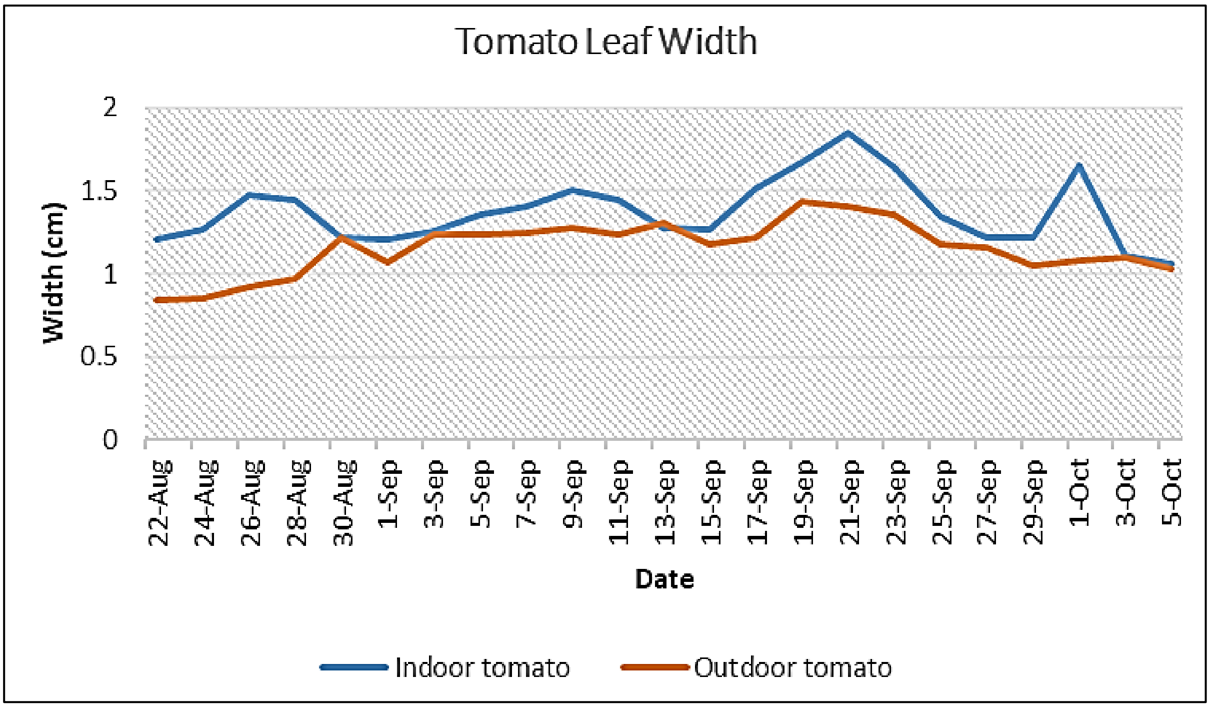
The leaf lengths of 3.2±0.1 cm and 3.9±0.1 cm in the tomato and lettuce plants were significantly lengthier indoors with compared to the tomato and lettuce plants 2.2±0.2 cm and 2.7±0.2 cm were observed in the outdoor system (Table 1. B). There was no significant difference could be observed in the automated indoor and outdoor systems for plants leaf widths of 1.1±0.03 cm and 0.3±0.03 cm were observed for the tomatoes and the lettuces respectively in the automated indoor system and 1.1±0.05 cm, 0.31±0.02 cm for the outdoor system. Similarly, a significant difference couldn't be observed for leaf amounts of 57.1±3.5 and 15.2±2.0 for tomato and lettuce in the automated indoor system and outdoor system 40.8±3.0 and 10.6±1.2. The difference between the tomato and the lettuce leaf widths was significant ($Pr=<0.0001$, $Pr\leq 0.05$) (Table 1.C & 1.D).

A significant difference was observed between the automated indoor tomato 30±0.9 and outdoor tomato 26±0.4 SPAD reading. Similarly, the automated indoor lettuce 23±0.3 and outdoor lettuce 17±0.5 SPAD readings were significantly different ($Pr=<0.0001$, $Pr\leq 0.05$). Significantly higher growth could be observed among the plant grown in the automated indoor system compared to the outdoor system.

Graphical representation of the plant growth rate of the tomatoes and the lettuces of the automated indoor system and the outdoor system could be observed in Figures 5 and 6. The growth parameters of the plant height and the leaf amounts of the tomatoes were continuously increasing comparatively higher for the automated indoor system than the outdoor system. This is because the indoor system automatically balances the nutrient solution so the plants can continuously receive a balanced solution. The leaf width of the automated indoor system was comparatively higher for tomatoes and its leaf lengths were also higher during the third month of planting.


Tomato Plant Height
Height (cm)
30
25
20
15
10
5
0
22-Aug
24-Aug
26-Aug
28-Aug
30-Aug
1-Sep
3-Sep
5-Sep
7-Sep
9-Sep
11-Sep
13-Sep
15-Sep
17-Sep
19-Sep
21-Sep
23-Sep
25-Sep
27-Sep
29-Sep
1-Oct
3-Oct
5-Oct
Date
Indoor tomato
Outdoor tomato


Tomato Leaf Length
Length (cm)
4
3.5
3
2.5
2
1.5
1
0.5
0
22-Aug
24-Aug
26-Aug
28-Aug
30-Aug
1-Sep
3-Sep
5-Sep
7-Sep
9-Sep
11-Sep
13-Sep
15-Sep
17-Sep
19-Sep
21-Sep
23-Sep
25-Sep
27-Sep
29-Sep
1-Oct
3-Oct
5-Oct
Date
Indoor tomato
Outdoor tomato



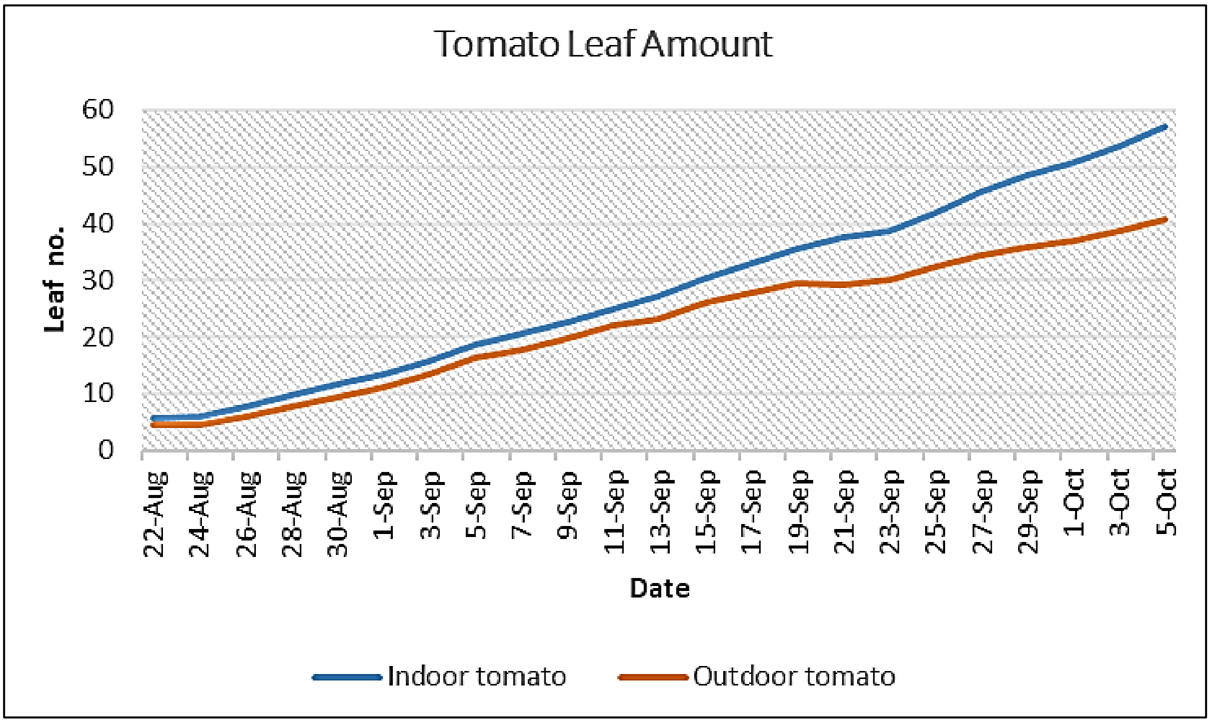
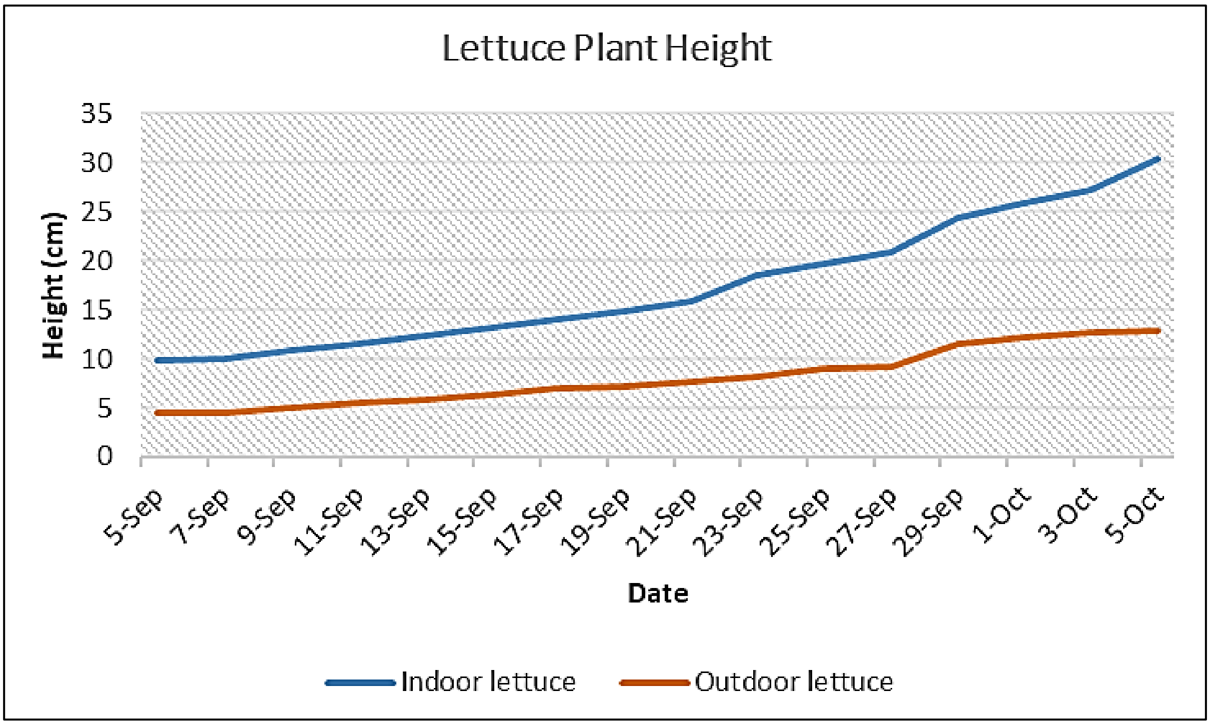
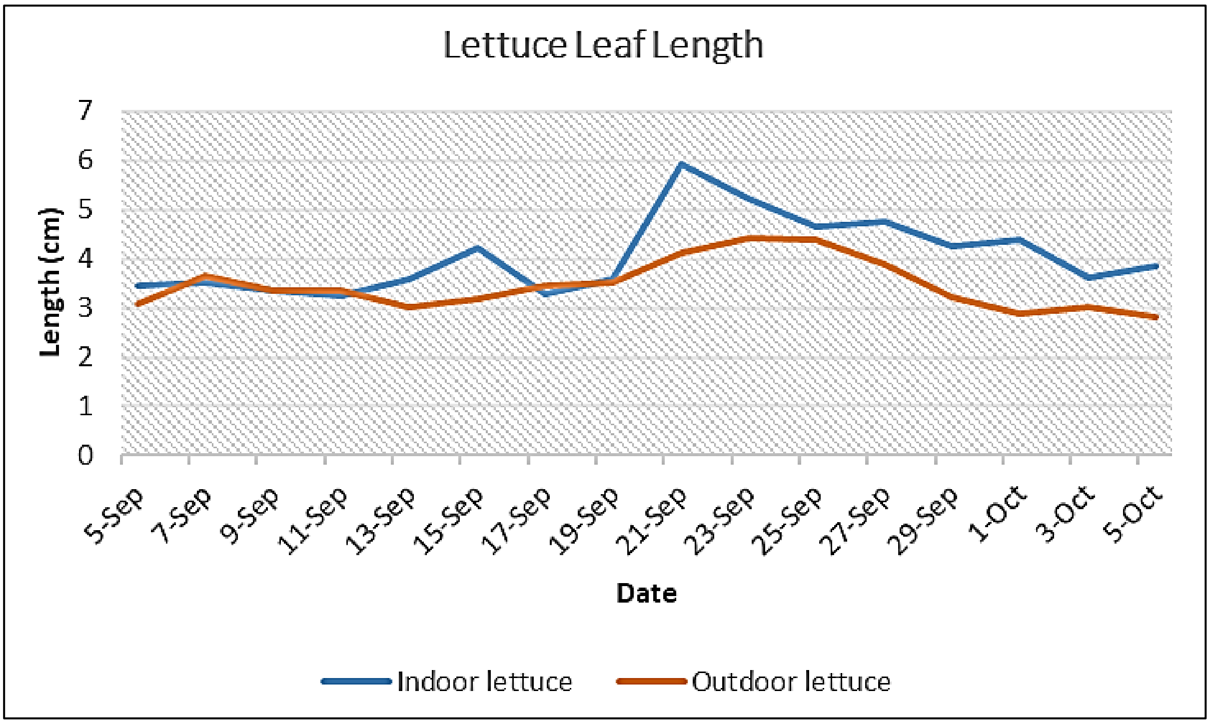
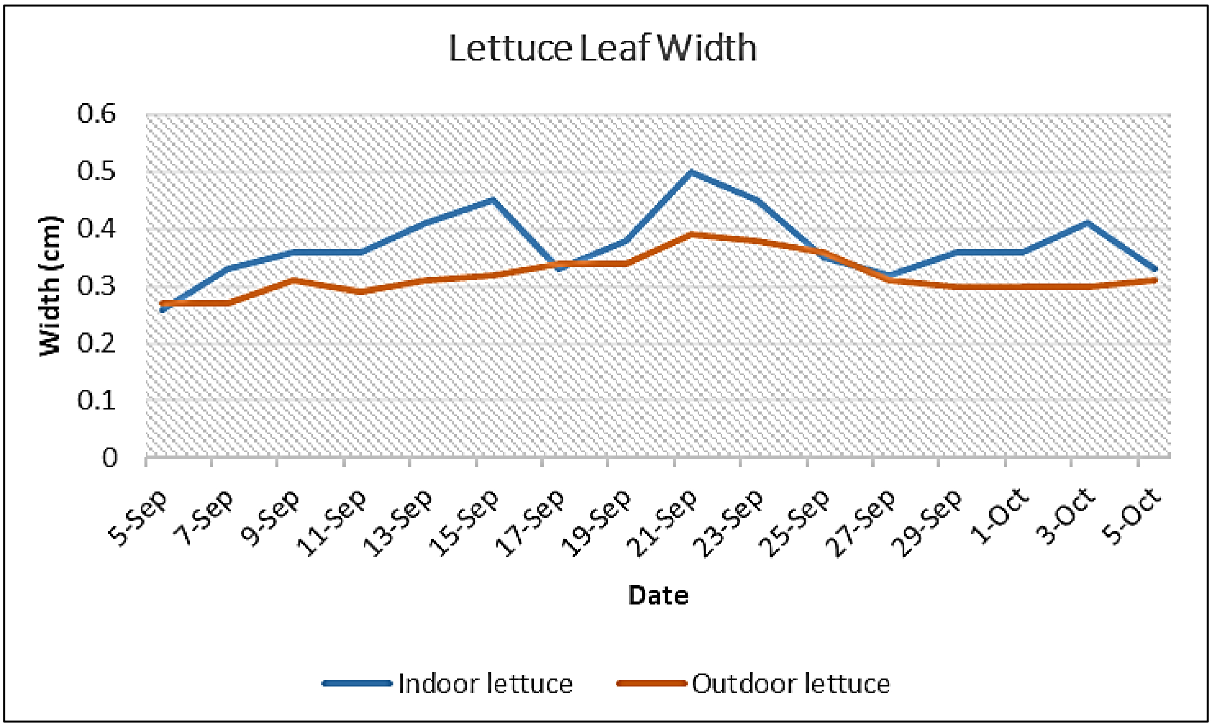


Figure 5. A) Plant height, B) Leaf length, C) Leaf width, D) Leaf amount of the tomato plants in the indoor automated system and the outdoor manual system


Lettuce Plant Height
Height (cm)
35
30
25
20
15
10
5
0
5-Sep
7-Sep
9-Sep
11-Sep
13-Sep
15-Sep
17-Sep
19-Sep
21-Sep
23-Sep
25-Sep
27-Sep
29-Sep
1-Oct
3-Oct
5-Oct
Date
Indoor lettuce
Outdoor lettuce


Lettuce Leaf Length
Length (cm)
7
6
5
4
3
2
1
0
5-Sep
7-Sep
9-Sep
11-Sep
13-Sep
15-Sep
17-Sep
19-Sep
21-Sep
23-Sep
25-Sep
27-Sep
29-Sep
1-Oct
3-Oct
5-Oct
Date
Indoor lettuce
Outdoor lettuce



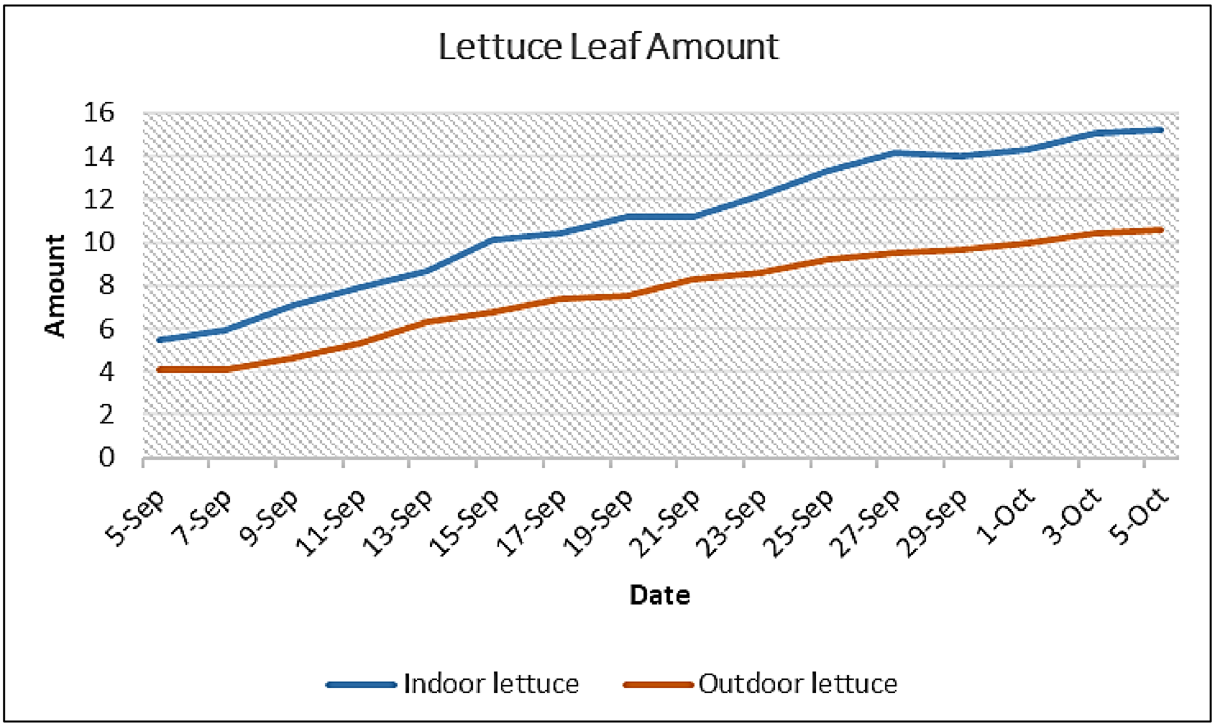
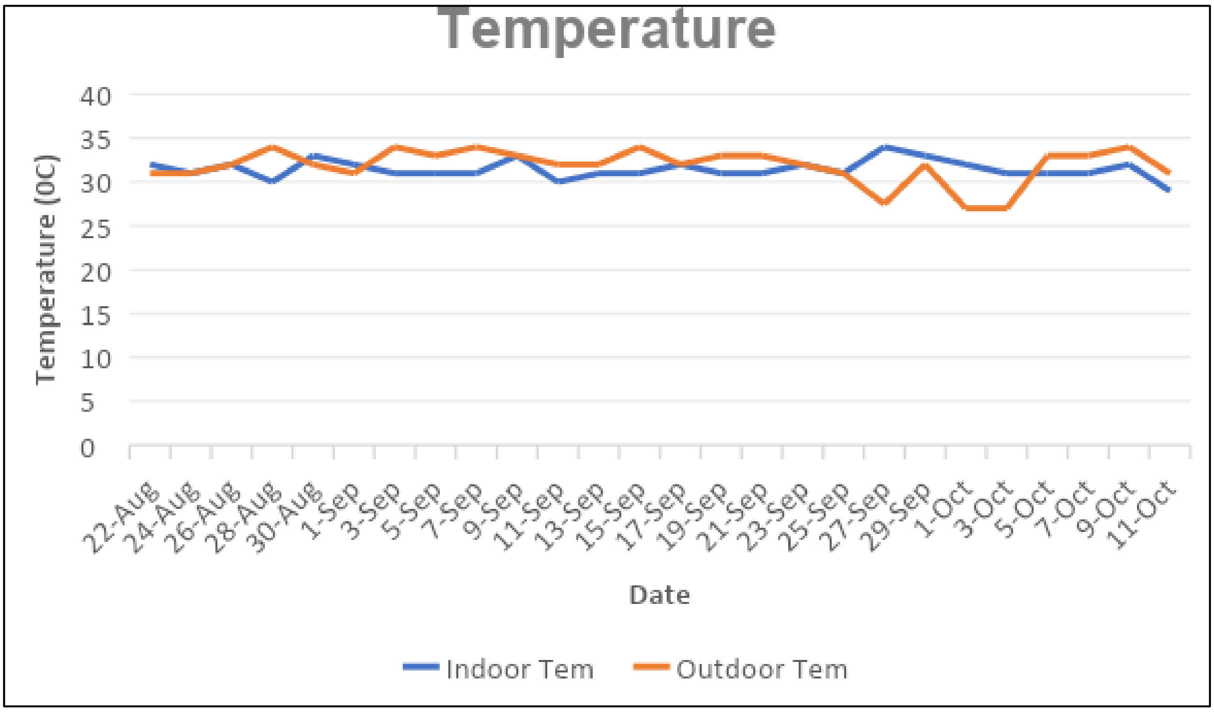
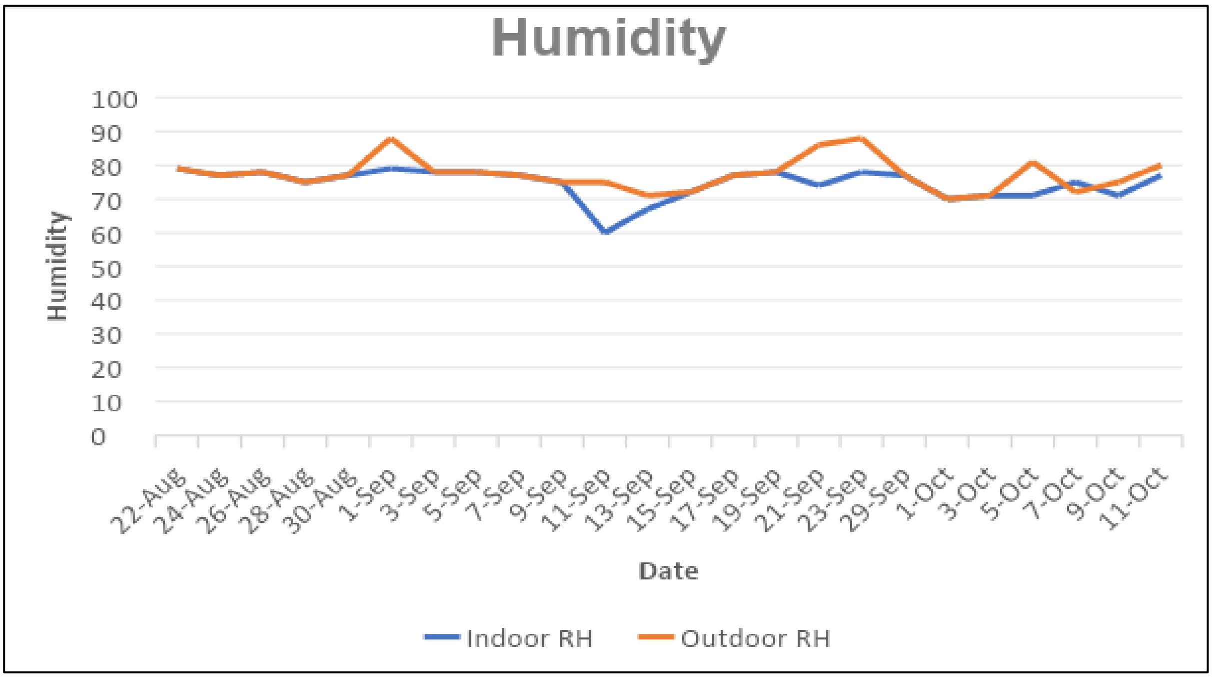


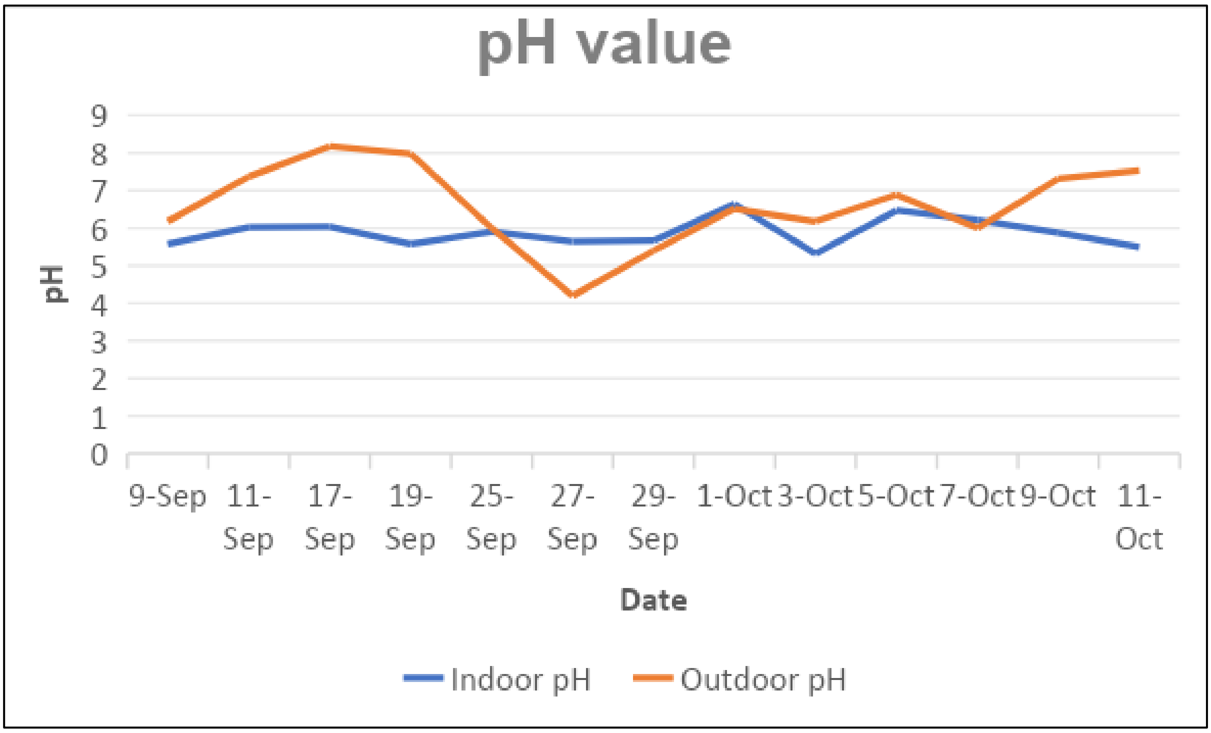
Figure 6. A) Plant height, B) Leaf length, C) Leaf width, D) Leaf amount of the lettuce plants in the indoor automated system and the outdoor manual system

The growth parameters of the plant height and the leaf amounts of the lettuces were also higher for the automated indoor system compared to the outdoor system. The leaf width and leaf lengths of the automated indoor system were generally higher for lettuces. It could be observed the fact of the effectiveness of automated indoor systems.

The system parameters of pH, EC, temperature, and humidity of the tomato and lettuce of indoor and outdoor systems were measured. The LUX meter reading was recorded during the experimental period and the average LUX value for the automated indoor system was 10±0.2 while 31±0.9 of the average LUX value was observed for the outdoor system.







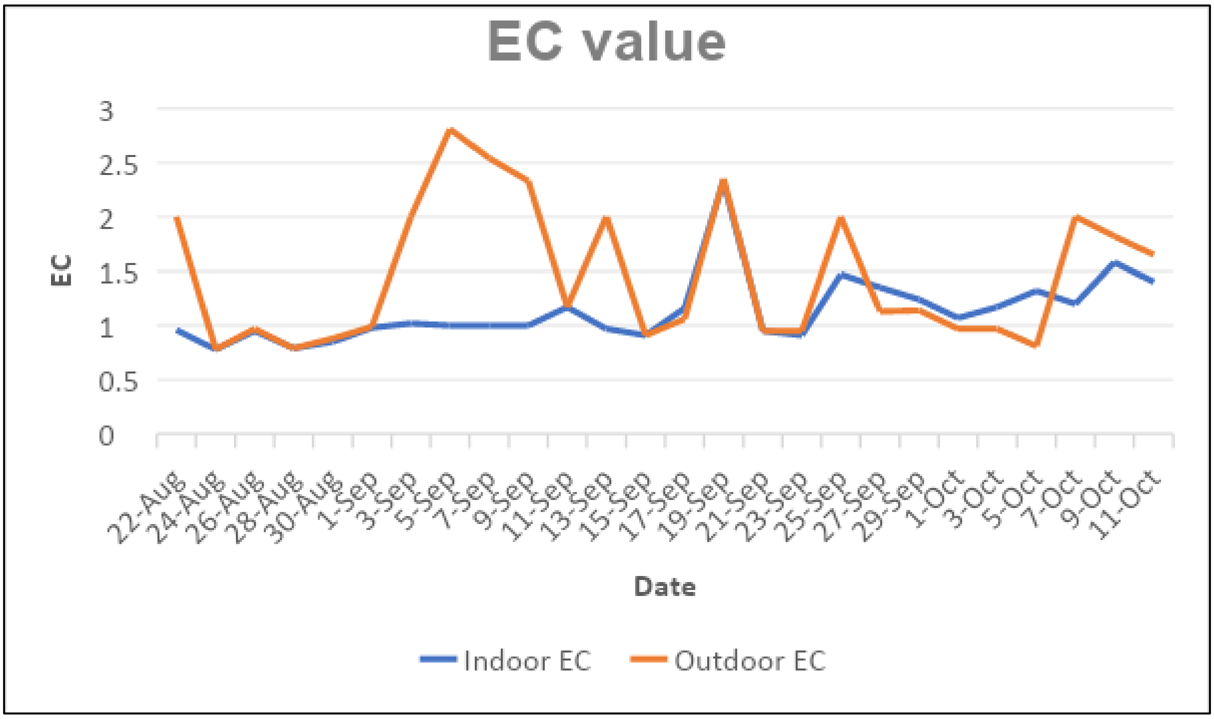


Figure 7. The system parameters of A) Temperature B) Humidity C) pH value D) EC value of the automated indoor system and the outdoor system

Figure 7. A shows the temperature variation of both systems with time. The temperature level of the indoor system is comparatively less than the outdoor system. Figure 7. B shows the variation of humidity in both systems. Humidity levels are comparatively uniform in both systems. Figure 7. C shows the variation of the pH level in both systems. pH value is between the uniform range during the experimental period; hence pH levels of outdoor systems fluctuate within a larger range. The EC level of the automated indoor system is

comparatively uniform compared to the outdoor system (Figure 7. D).

The EC value of the outdoor system has fluctuated largely through the experimental period. The uniform pH and EC levels and the comparatively uniform temperature and humidity levels played an important role in optimum plant growth despite the varieties grown in the automated indoor system. The specialty of the automated system was the differences between the heights of each raw of the system which could emphasize the fact that the same plant system can successfully accommodate different plant varieties with different plant architectures.

The temperature of the indoor systems varied in the 30° C-32° C range while in the outdoor system, It was varied in the 29° C-34° C range. Both the temperature levels and the humidity levels were comparatively uniform in the indoor system compared to the outdoor system. The pH of the automated indoor system was 5.5-6.5 but in the outdoor system, pH varies in a large range of 4.2-8.18. The EC in automated systems EC varies in 1.5-2.5 dS/m and outdoor system EC changed in the 0.93-2.81 range. The pH and EC values of the indoor system were comparatively uniform to the outdoor system.

CONCLUSION

The present study aimed to address the need for a sustainable food ethic that promotes the health of our food, bodies, and environment while minimizing the use of chemicals. Hydroponic farms emerged as a viable solution, offering soilless agriculture with significant advantages over traditional farming practices. In this regard, a fully automated hydroponic system, utilizing the Arduino platform, open-source software, and various sensors, was developed to make hydroponics accessible and manageable for everyday users.

The automated hydroponic system successfully integrated an IoT network for remote monitoring and control, ensuring optimal conditions for plant growth. This system demonstrated several benefits, including precise control over essential growth elements, customization options for different plant species, and independence from external environmental factors. Moreover, it proved to be compact and cost-effective for consumer use, outperforming other systems through its complete automation.

The results obtained from the experimentation revealed significant improvements in growth parameters for tomatoes and lettuces in the automated indoor hydroponic system compared to the outdoor system. Specifically, the plant height and leaf amounts of tomatoes exhibited continuous growth, with higher values observed in the indoor system. Similarly, lettuces displayed enhanced growth in terms of plant height, leaf amounts, leaf width, and leaf lengths in the indoor system.

Based on the findings, it can be concluded that the automated indoor hydroponic system effectively promotes plant growth and productivity compared to traditional outdoor systems. This experiment provides evidence supporting the effectiveness and efficiency of indoor hydroponics. Additionally, the integration of an IoT platform enables users to access real-time data and reduces the need for human intervention, resulting in time-saving benefits.

In conclusion, this study highlights the potential of hydroponics as a sustainable farming method and emphasizes the importance of automation and IoT integration in maximizing its benefits. The findings encourage further exploration and implementation of indoor hydroponic systems to meet the growing demand for sustainable and efficient food production.

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