Development and experiment of the intelligent control system for rhizosphere temperature of aeroponic lettuce via the Internet of Things

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Abstract: Currently, in the conventional aeroponic system the collection of data for crop performance is quite slow, whereas such data are typically collected manually. Correspondingly, the root zone temperature is one of the most important factors affecting plant growth in aeroponics cultivation. This study aimed to obtain temperature and relative humidity data inside an aeroponic system based on the Internet of things (IoT) and automatically cool the root zone using a novel low-cost effective technique for cooling via a cooling fan connected to the Arduino board. The results revealed that the newly designed system could monitor and record the data in real-time on an internet server per hour. Furthermore, the temperature and humidity data can be displayed on the smartphone application, and be sent to the personal email weekly as an excel sheet. This system was able to maintain the temperatures inside the roots chamber between 28.7°C-29.2°C while the maximum external temperature was 38.1°C, and the average temperature in the traditional aeroponics system was fluctuating between 29.5°C-31.5°C. The newly automated cooling system root zone system of this study showed an optimization of lettuce growth characteristics. It significantly increased the lettuce absorbance of inorganic nutrients such as N, P, and K by 45.5%, 66.6%, and 45.0%, respectively, and revealed an increment of fresh weight, total chlorophyll, ascorbic acid, total carbohydrate, and total amino acids by 131.0%, 26.2%, 41.9%, 30.7%, 6.2%, respectively in comparison with the conventional aeroponic system. Therefore, this study may play a significant role in the aeroponic monitoring and control, for providing more suitable growth parameters and achieving the least human interaction.

Keywords: aeroponics, IoT, rhizosphere temperature, lettuce, intelligent control system

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1 Introduction

Aeroponics is considered a new plant growing technique in modern agriculture. This system belongs to soilless culture, where the plants are grown without soil, the roots are suspended in air and the nutrient mixture in the form of fine mist is sprayed through nozzles[1]. This method has been utilized successfully for the production of different species of horticultural crops including lettuce[2]. In the conventional aeroponic system, growers use their skills, knowledge, and judgment to regulate and preserve the parameters such as EC, pH, temperature, light intensity, and humidity level through several tools and check the readings which need a labor-intensive and time-consuming task.

In aeroponics systems, the root zone temperature is considered one of the key and critical factors significantly affecting plant growth and development. In the aeroponic system, the optimum growth chamber temperature should not be more and less than 30°C and 4°C, respectively, for successful plant growth[1]. In addition, roots are more thermosensitive than shoots[3]. Temperate and subtropical crops have been successfully grown in a tropical greenhouse by cooling only their roots[4].

The aeroponic system can be provided with a wireless sensor and actuator network (WSN) for monitoring the key parameters at lower labor costs, time, and low levels of technical knowledge. The wireless sensor and actuator network proposes many advantages including faster response to confrontational climatic conditions and better-quality control of the crop that produces at a lower labor cost.

However, the monitoring system also offers a range of information that could be required by plant scientists or growers to provide a better understanding of how these environmental and nutrient parameters correlate with plant growth. Lakhiar et al.[1] stated that the integration of intelligent agriculture systems (like WSN) could be an effective approach for solving complex problems of agriculture domains. It provides full control of the system, not by constant manual attention from the operator but to a large extent by wireless sensors.

Although the importance of the temperature factors, few studies showed the utilization of Arduino-based IoT for automatic control and monitoring. Wellem and Setiawan[5] introduced temperature measurement and monitoring mechanism with the help of the Atmel Atmega 8385 microprocessor system and LM35 temperature sensor. Masstor[6] proposed a case study for an alarm system based on temperature and humidity sensing. Arduino controlled GSM/GPRS module was recommended, but temperature measurement was not accurate in the system. Kesarwani et al.[7] carried out a case study on systems of temperature control using triode for alternating current (TRIAC), microcontroller, and bridge rectifiers. In this concern, Nandagiri and Mettu[8] suggested a temperature control mechanism, and it was declared that it is really useful for IoT-related applications. From all of these researches, we found that temperature control is also an automatic way of

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monitoring that has not been attempted by the researchers.

Moreover, lettuce (*Lactuca sativa* L.) is a drought-tolerant winter annual, well-adapted to Europe, non-tropical parts of Eurasia and North Africa, North America, and South Africa[9]. Lettuce plant contributes to diet since on a fresh weight base 95% of the plant is water. However, lettuce is an extremely popular vegetable, and when overall bulk is considered it is rated fourth behind tomato, citrus, and potato in terms of overall contribution to nutrition. Lettuce provides significant amounts of phosphorus, iron, sodium, and potassium and other nutrients are present in varying amounts in the different lettuce sorts[10].

Because lettuce is a temperate plant, growing it under tropical conditions decreased head biomass and quality[11]. He et al.[12] reported increased total leaf number and shoot fresh mass of lettuce plants grown in 20°C cooled root zone when compared to plants in the non-cooled root zone. Choong et al.[11] found that the low productivity of lettuce growing in such warm conditions has been correlated with reduced root growth where the roots cannot adequately supply water and nutrients to the shoot, thereby limiting photosynthesis. Sago et al.[13] mentioned that root nutrient absorption rate could be raised by controlling the cultivation environment, and root-zone temperature is believed to be an important environmental factor that could change root water and nutrients absorption rates. Also Sago et al.[13] found that the increased root zone temperature of about 30°C could decrease the fresh weight of the lettuce lower than lettuce grown at 25°C and 20°C, however, increase the absorption of some nutrients such as zinc at 30°C more than 25°C and 20°C.

Jie and Kong[14] stated that the three lettuce cultivars in their study had great formation of compact heads when the root zone was cooled appropriately. Also, all the three lettuce cultivars whose rootzones were maintained at lower temperatures had higher growth and photosynthetic capacity hence leading to the formation of compact heads. They concluded that *Lactuca sativa* L. is a temperate plant, certain cultivars can be grown normally in the tropics aeries under-maintained rootzone temperatures below 25°C. Carotti et al.[15] demonstrated that the fresh weight, dry weight, and specific leaf area of the lettuce grown in the aeroponic system were increased when the root zone temperature was maintained at 28°C. He et al.[16] indicated that cooling the root zone of salad rocket (*Eruca sativa*) plants protected their photosystem II from photoinhibition during midday in the tropical greenhouse. Also, they mentioned that the plants grown under 20°C-25°C root zone temperature had the highest shoot fresh weight, photosynthetic gas exchange, midday chlorophyll (Chl) fluorescence Fv/Fm ratio, and nutrient contents such as potassium (K), calcium (Ca), magnesium (Mg) and iron (Fe). In addition, the total phenolic compounds were at the lowest values in the case of cooling the root zone at 20°C, meanwhile were at the highest values at ambient temperature (without cooling for the root zone). Furthermore, the authors concluded that the cooling of roots is a possible method for the cultivation of *Eruca sativa* in the tropic, which enhances the content of dietary minerals in shoots. Also, they concluded that tropical high ambient temperature reduced the productivity of temperate plants, temperate vegetable crops such as lettuce have been successfully grown in tropical areas by only cooling their root zone.

This study aimed to design an aeroponic system able to wirelessly collect temperature and humidity data based on IoT technology for real-time monitoring on smartphones. It could also send the data to a computer as an email, as well, attached this system with unconventional cheap automated control for cooling root zone by small fan turns ON/OFF automatically, by detecting the certain limit of temperature. In addition, the effects of the proposed system were observed for lettuce growth, its characteristics, photosynthetic pigment, inorganic components, total carbohydrate, and total amino acids content by comparing the systems with the traditional aeroponic system.

2 Materials and methods

2.1 Experiment site

The experiment was conducted in the greenhouse for 40 d from the end of August to the beginning of October 2020 over a roof building with an area of 6×4 m^2, in Giza, Egypt. The roof of the greenhouse was covered with a shading net to lower the temperature in the greenhouse. The roof and doors were properly sealed to keep off insects and diseases. The experiments were exposed to ambient environmental conditions. Climate variables such as maximum, minimum temperature, and humidity were recorded by WSN based IoT technology on daily basis during the experimental period.

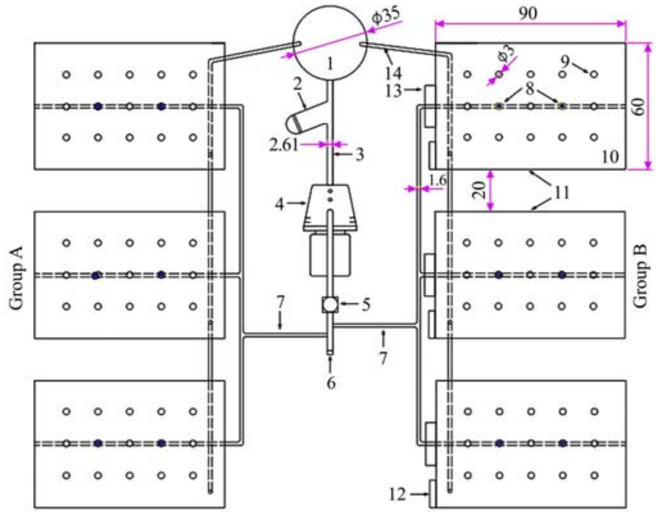
2.2 Plant material and growth conditions

Lettuce seeds (*Lactuca sativa* L. cv. ‘Ifram’, Agro-limited Seeds Company, Egypt), were germinated in seedling trays, each tray consisting of 200 cells. 2-5 seeds were inserted in each cell manually, and the trays were filled with Peat moss mixed with compost 1:1, After the seed planting the trays were irrigated and exposed to LED light inside the room with a maintained temperature of 34°C during the day, and 29°C at night. After one week the seedlings were grown with two true leaves. The trays were transmitted into the place of the experiment under indirect solar illumination for acclimating to the ambient environmental conditions of temperature, and humidity. The seedlings were irrigated with a foliar nutrient solution every 3 d. After 1 month of the planting of the seeds, the seedlings were transplanted into sponge holders. Shoot-zone was exposed to fluctuating ambient temperatures, the mean ambient temperature and relative humidity throughout the growing period were (36±1)°C, and (44±5)% respectively relative humidity at day time, while the mean ambient temperature at night was (29.9±1)°C with (64±5)% relative humidity, under 80% prevailing solar radiation. The nutrient solution was sprayed the same as in the previous study of El-Ssawy et al.[17] with pH fluctuated from 6.3 to 7.3 and EC fluctuated from 2.1 mS/cm to 2.3 mS/cm.

2.3 Aeroponics system

The aeroponics system was consisting of six chambers, each chamber 90 cm long and 60 cm wide with a height of 30 cm. The chambers are made up of Styrofoam sheets with lids having 5 cm thickness. The lids were prepared with holes for plant holders (15 holes/lid), which were made up of polyurethane material. The distance was maintained at 15×15 cm^2.

For the recycling of nutrient solution, the fertigation system was consisting of a cylindrical polyethylene tank with a capacity of 80 L was used. The nutrient solution was pumped using a pump (Keny JET-100L, Taizhou Factory, China) through 16 mm polyethylene tubes installed inside the system connected to foggers. In the system, there were two mini mist one-way foggers (ZN 1216, China) fixed at the bottom of each box. The diameter of the spray circle of the foggers was 0.5 m, 8 L/h flow rate, and 2 bar operating pressure. The spraying time of 1 min and spraying interval of 5 min was kept constant throughout the experiment[18]. The components of the system are shown in Figure 1.



1. The nutrient tank 2. Screen filter 3. PVC plastic main line1inch 4. Pump 1hp power 5. Fine filter 6. Plug (main line end) 7. PE delivery tube 16mm diameter 8. Foggers (nozzles) 9. Plant holder or holes 10. Plant array or Styrofoam lid 11. Styrofoam chamber (root chamber) 12. IoT devices with sensor inside the root chamber 13. Cooling fan 14. PE return tube 16 mm diameter

Note: Group A is an ordinary aeroponic system without cooling the root zone (NCRz); Group B is an automated cooled root zone (ACRz).

Figure 1 Components and implementation of the aeroponic system

2.4 Experiment design and implementation

Two experimental groups encoded as A and B were demonstrated each group had three boxes, and each box contained 15 lettuce seedlings. Group A is an ordinary aeroponic system without cooling the root zone (the control or NCRz), Group B is an automated cooled root zone (ACRz) by cooling fan based IoT monitoring system. Both two groups were sprayed with the same nutrient solution and exposed to the same environmental conditions from temperature and humidity. The components of the system are shown in Figure 1.

2.5 Automated cooling system based IoT monitoring

The system was designed to monitor the temperature and humidity inside the aeroponic root chambers and the surroundings of the plants (outside the aeroponic chambers), then transmit this data wirelessly through the Wifi communication technology into a server on the internet or cloud server, in this study's case was Aliyun server platform and received it by a smartphone application-based Android system as shown in Figure 2.

Figure 2 Screenshot of Blynk application interface on smart phone during live monitoring of temperature and humidity

The smartphone application showed the values of temperature, humidity, and their charts in real-time. Also, the proposed system was able to send a weekly report via email as an excel datasheet. The data were collected by sensors every second and the Blynk application sends the data as a weekly report on average per hour. Furthermore, this system was able to control the temperature inside the root chamber by automatically running a cooling fan in real-time. In case, the temperature exceeds 30°C inside the root chamber, the fan continues running until the temperature decreases below 30°C and then stops working, and repeats this action as a loop, as shown in Figure 3.

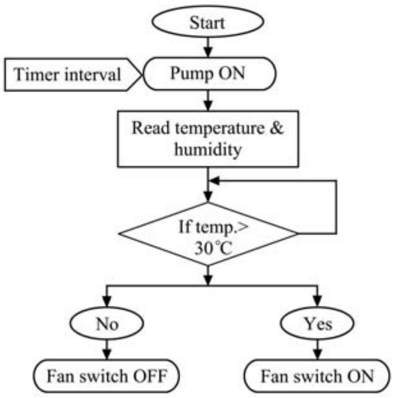


Figure 3 Flow chart of temperature control inside the root chamber of aeroponic system

2.6 System hardware components

The ESP8266 Node MCU microcontroller with a Wifi module amalgamated on it .For the measurement of temperature and humidity, the sensor DHT11 was used. The measuring ranges of the sensor are 0°C-50°C (±1°C) in temperature, and 0%-100% (±5%) in relative humidity. The relay module was used for the ON/OFF switch for controlling the cooling fan. The cooling fan features were (12.0×12.0×3.8 cm^3, DC motor 12 V, 0.22 A, speed of 3200 r/min, air volume of 4.245 m^3/min or 0.07 m^3/s, air speed of 6.8 m/s). The Internet gateway (router) was considered the link between the IoT devices and the server cloud on the internet. Jumper wires connect the sensors with the microcontroller and relay module with the cooling fan. Furthermore, for the supplying of power to the microcontroller and cooling fan two types of adaptors; 9 V, 1 A, and 12 V, 1 A were used, respectively. The cooling fan was fixed on the smallest side of the aeroponic boxes. The hardware components are connected as shown in Figure 4.

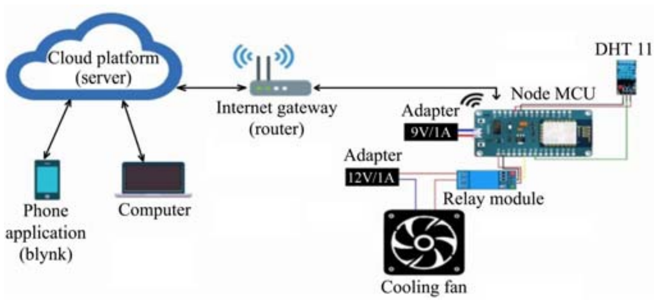


Figure 4 Components of IoT device used in monitoring temperature, humidity, and control the temperature of the aeroponic system, with transferring the data into a smart phone or computer

2.7 System software components

The demonstrating system software of this study was called mixly and Blynk software. Mixly is a code programing software like Arduino IDE, but it is simpler than Arduino IDE because it has many code blocks. The codes of the proposed system were created by compositing these blocks together to get the right code needed for programming the node MCU. The Blynk application was used (Figure 2) for android smartphones for data monitoring (temperature and humidity). Blynk is an open source IoT platform for designing to carrying out applications of IoT on smartphones.

2.8 System measurements

2.8.1 Temperature and humidity

The temperature and humidity of the ambient air condition and inside the root chambers of the ACRz system were collected on average every 1 h by the WSN based on IoT technology. The temperature and humidity of rootzone chambers in system NCRz were measured by ordinary temperature and humidity sensors (HTC-2 temperature and humidity sensor, Yueqing Kampa Electric Co., Ltd., China) with the same sensitivity as the DHT11 sensor used in the IoT system.

2.8.2 pH and EC

The pH and EC of the nutrient solution were measured every day along the period of cultivation to ensure their definite levels by a digital pH meter (ATC, China, with resolution of 0.1pH, and accuracy of ±0.1), and a 3in1 TDS device (Water World Company, USA) to measure EC with an accuracy of ±2%. After 40 d of transplanting, randomly collected plants were stored in plastic bags and immediately taken to the laboratory for analysis.

2.9 Plant growth and morphology

The plant morphology was examined through the plant height (cm), stem diameter (cm), leaf length (cm), leaf width (cm), leaf number (leaf /plant), and root length (cm) with the help of Vernier caliper (accuracy of 0.1 mm) and steel measuring scale (accuracy 1 mm) tools, while the fresh and dried shoot and root weight (g/plant), were measured by precision balancer (ADAM PGL 303, Adam Equipment Co., USA, with a sensitivity of 0.001 g).

2.10 Photosynthesis pigments

Randomly three plants collected from each replication were used to measure the photosynthesis pigments. The samples were treated as in the Wellburn method[19], then the pigment quantification was performed by spectrophotometry method, at 665 nm and 646 nm for chlorophylls a, b, and 470 nm for carotenoids. The digital spectrophotometer used was Thermo Scientific Helios Beta Spectrophotometer P/N 9423UVB1002E (18945 L33), USA. The equations were used by researcher Wellburn[19] to calculate the pigment contents. Data were expressed as the mass of pigment per mass of fresh leaf.

2.11 Inorganic components

The determination of essential macro and micro elements represented in N, P, K, Ca, Mg, Cu, Fe, Mn, and Zn[20] were carried out on the dry material of lettuce leaves. The digestion solution for the dry material of lettuce leaves was prepared as reported by Piper[21].

The total nitrogen content of the dried samples was determined by using the modified-micro-Kjeldahl method as described by Peach et al.[22] and Helrich[23]. Phosphorus was determined calorimetrically by using the chlorostannous molybdophosphoric blue color method in sulphuric acid, according to Jackson[24]. The measurements were by the Spectrophotometer with air-acetylene, fuel (model SP-1900, Pye Unicam, USA), and flame atomic emission spectrometer. Potassium concentrations were determined by using the flame photometer apparatus (CORNING M 410, Corning Incorporated, Germany). The N, P, K, Ca, and Mg content of the dried plant material, is expressed as (%), while Cu, Fe, Mn, and Zn contents of the dried plant material are expressed as mg/L.

The total phenolic contents were determined spectrophotometrically according to the Folin-Ciocalteu reagent colorimetric method[25] and presented as (%) of plant tissue.

2.12 Ascorbic acid (Vitamin C)

Ascorbic acid (mg) was determined per 100 mL of fresh leave juice, according to Helrich[23] method.

2.13 Total carbohydrates

The total carbohydrates in the lettuce plant were determined by phosphomolybdic acid method according to Helrich[23].

2.14 Total amino acids

The amino acid analysis was conducted by the ultra-performance liquid chromatography (UPLC) method[26].

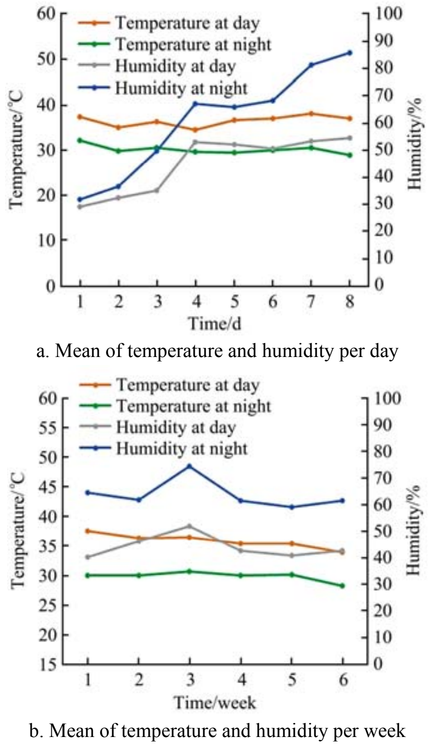
2.15 Statistical analysis

Results were subjected to one-way analysis of variance (ANOVA) of the general linear model (GLM) using SAS (1999) statistical package and WASP analysis software statistical package. The results were subjected to a mean±standard error (S.E.) (p≤0.05). t-test was used to evaluate statistical significance.

3 Results

3.1 Collected temperature, humidity, and the effect of cooling fan on temperature and humidity inside the root chambers

Figure 5a demonstrates the mean ambient weather temperature and relative humidity of 24 h (day and night) for 8 days (the second week after transplanting). The results reveal that the maximum day temperature of 38.1°C was observed on the 7th day, while the maximum relative humidity of 54.6% was calculated on the 8th day. The maximum temperature at night was on the 1st day (32.2°C), while the maximum relative humidity at night was (85.7%) calculated on the 8th day. Moreover, the daytime minimum temperature and humidity of 34.6°C and 29.1%, respectively were observed on the 1st day. Additionally, the minimum temperature and humidity at night were 28.9°C and 31.8% on the 8th and the 1st day, respectively.



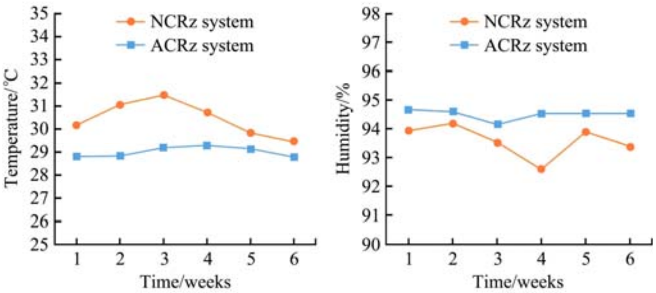
b. Mean of temperature and humidity per week

Note: The day is split into two periods, the period of day (morning) which is from 6:00 am to 5:00 pm, and the period of night starts from 6:00 pm to 5:00 am.

Figure 5 Collected data on temperature and humidity of the ambient weather conditions by WSN based IoT system

The mean ambient weather temperature and relative humidity per week as long as the crop lasts are shown in Figure 5b. From the figure, it can be observed that the maximum mean temperature and humidity during daytime were on the 1st week (37.4°C), and on the 3rd week (52.1%) respectively. The maximum mean temperature and relative humidity at night were observed at 30.7°C and 74.5% in the 3rd week. While as, the minimum mean temperature at daytime occurred in the 6th week (33.9°C), and the minimum mean of humidity at daytime happened in the 1st week (40.3%). Additionally, the minimum mean temperature at night was in the 6th week (28.2°C), while the minimum mean of relative humidity at night was in the 5th week (59.3%).

Figure 6 presents the temperature and humidity of the root chambers in both NCRz and ACRz systems. Figure 6a shows the mean temperature per week in the NCRz and ACRz systems. From the figure, it can be seen that the cooling fan significantly reduced the temperature inside the root chambers of the ACRz system compared with the NCRz system. The temperature inside the root chambers in the ACRz system was stable in the range of 28.7°C-29.2°C, while the mean temperature in the NCRz system (control) was fluctuating between 29.5°C and 31.5°C. The reduction in root zone temperature was 2.7%-7.3%. Figure 6b shows that the relative humidity of the root zone of the ACRz system is between 94.1% and 94.6 %, while the humidity in the root zone inside the NCRz system fluctuated between 92.6% and 94.2%. Furthermore, the system of this study ACRz achieved more stability in the relative humidity during the cultivation period than the control system (NCRz).



a. Mean of temperature per week of the NCRz system (control) and ACRz system

b. Mean of humidity per week of the NCRz system and ACRz system

Figure 6 Effects of automated cooling fan on the temperature and humidity of the root chambers of ACRz system, and comparing with NCRz system

3.2 pH and EC

The analyzed data of pH and EC is shown in Figure 7. The mean pH values of the nutrient solution were 6.5 as long as the cultivation period, the pH values exceeded 6.5 in the first two weeks then reduced below the level of 6.5 in the remaining weeks. The analyzed data for the EC values of the nutrient solution is shown in Figure 7. The results reveal that the EC values oscillated between 2.14 mS/cm to 2.33 mS/cm with a mean of 2.2 mS/cm. The reduction in pH value was a result of using a mixture of phosphorus and nitric acids to keep the pH in a range suitable for lettuce growth.

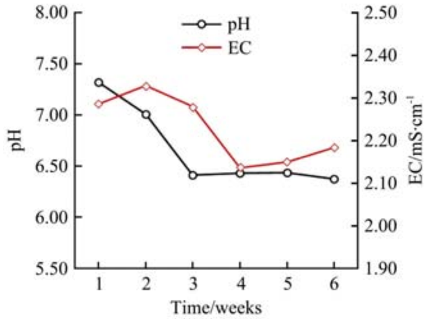


Figure 7 Mean of pH and EC values per week along the cultivation period

3.3 Plant morphology

Many growths and morphological characteristics in aeroponically grown lettuce demonstrated a significant difference between the noncooled root zone (NCRz) and automated cooled root zone (ACRz) as shown in Figure 8.

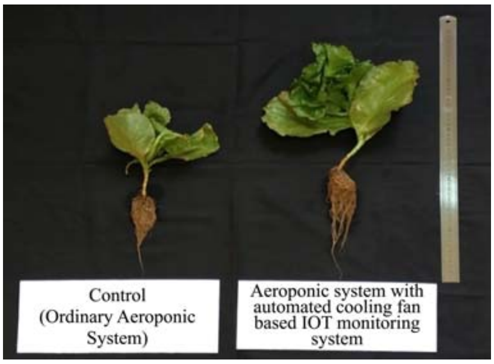


Figure 8 Comparison of the plants cultivated in NCRz (control) and ACRz systems, the ruler used was 50 cm long

The analyzed results of plant height are listed in Table 1. The data show non-significant differences between the two systems (NCRz and ACRz). Where the mean plant height cultivated in the NCRz system was a little lower than the plant cultivated in the ACRz system. Tables 1 and 2 also, show a non-significant difference under the two systems on leaves length, shoot length, stem diameter, and root dry weight. However, the values of the mentioned parameters were a little bit bigger in the ACRz than in NCRz. While the data for the number of leaves in Table 1 show significant differences between the two systems NCRz and ACRz at p<0.01, CD(0.01)=3.069. Leaves width (cm) data showed significant difference at p<0.05 with CD(0.05)=2.313. The data on root length also show a significant difference at p<0.01, CD (0.01)=4.009, where the root length in the ACRz system was longer than the root length in the NCRz system by 8.62 cm (increase in length by 66.9%) as shown in Figure 8. In Table 2 the shoot fresh weight data showed a significant difference at p<0.01, CD (0.01)=14.785. The fresh weight of the shoot in the ACRz system was increased by 134.8% in the comparison with the NCRz system with a difference of 19.9 g. Results of dry weight (Table 2) revealed significant differences in plant dry weight between the two systems, the significant difference was at (p<0.01), CD(0.05)=1.452.

Table 1 Effects of NCRz and ACRz systems on plant height, leaves number, leaves length, leaves width shoot length, and root length

Morphology characteristics	Plant height/cm	Leaves No. (N)	Leaves length/cm	Leaves width/cm	Shoot length/cm	Root length/cm
Non cooled root zone (NCRz)	32.3±1.17^{a}	14±0.00^{b}	10.67±0.33^{a}	7±0.50^{b}	19.4±1.07^{a}	12.9±0.48^{b}
Automated cooled root zone by fan (ACRz)	38.7± 2.13^{a}	20.3±0.67^{a}	13.67±1.09^{a}	10.7±0.67^{a}	21.5±1.50^{a}	21.5±1.50^{a}

Note: All results represent the means of three replicates±standard errors. Different letters a-d in the same column indicate significant differences or Critical Difference (CD) compared by t-test (p<0.05, n=6) from the given means. The same as below.

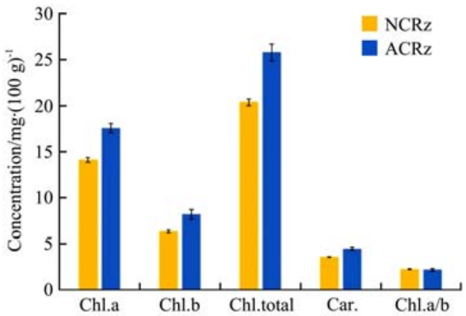
Table 2 Effects of NCRz and ACRz systems on stem diameter, shoot fresh weight, root fresh weight, shoot dry weight, and root dry weight

Morphology characteristics	Stem diameter/cm	Shoot fresh weight/g	Root fresh weight/g	Shoot dry weight/g	Root dry weight/g
Non cooled root zone (NCRz)	0.48±0.02[a]	15.16±4.09[b]	2.16±0.18[b]	1.39±0.36[b]	0.42±0.09[a]
Automated cooled root zone by fan (ACRz)	0.60±0.06[a]	35.06±3.41[a]	6.80±1.07[a]	2.96±0.38[a]	1.44±0.36[a]

The greater value of the dry weight of the shoot was found in the ACRz system compared to the NCRz system with a difference of 1.564 g (an increase of 114%). Furthermore, the results of root fresh weight are presented in Table 2. It was found a significant difference at (p<0.01), CD(0.05)=3.017. The root fresh weight in the ACRz system was higher than in the NCRz system by 4.64 g. (increased by 214%).

3.4 Photosynthesis pigments

The analyzed results of photosynthesis pigments of lettuce leaves showed a large variety of chlorophyll a (Chl. a), chlorophyll b (Chl. b), total chlorophyll, carotenoid contents, and chlorophyll a/b in Figure 9. The result revealed that the Chl. a content of the plants for the ACRz system was higher than in the plants of the NCRz system (increase by 24.7%), and there was a significant difference at p<0.01, CD(0.01)=2.581. Similarly, Chl. b content was higher in the ACRz system than the NCRz system (increase by 29.5%) and showed a significant difference at p<0.01, CD(0.01)= 1.530. Total chlorophyll exposed at a higher value inside the ACRz system than its value in the NCRz system (increase by 26.2%) and showed a significant difference at p<0.01), CD(0.01)=4.448. Also, the data of carotenoids showed the highest value in the ACRz system, which was higher than the carotenoid value in the NCRz system (increase by 24.6%), and found a significant difference at p<0.01, CD(0.01)=0.779. The Chl. a/b results showed a non-significant difference between the two systems.



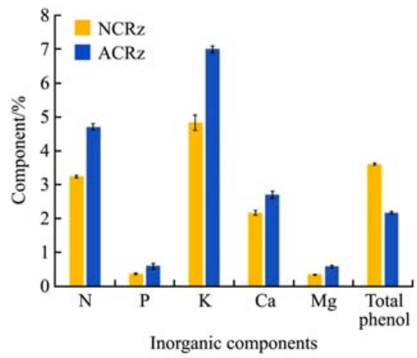
Note: Chl. a: Chlorophyll a; Chl. b: Chlorophyll b; Car.: Carotenoid.

Figure 9 Effect of the ACRz, and NCRz systems on photosynthesis pigments

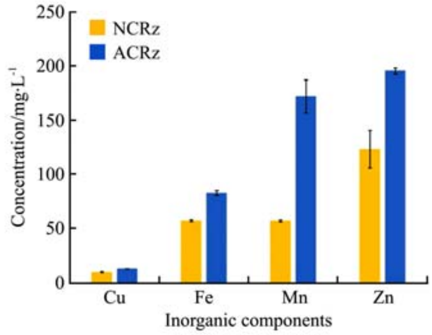
3.5 Inorganic components (mineral nutrients)

The results in Figure 10a present the nitrogen (N) contents obtained in the lettuce leaves. It is clear that between the two systems, the plants cultivated in ACRz exhibited a higher content of nitrogen. Contrarily the plants cultivated in the NCRz system had lower nitrogen content. N content of leaves cultivated in the ACRz system showed an increase of 45.5% compared to the NCRz system. The treatment of ACRz system showed significant difference at p<0.01, CD(0.01)=0.485. The results of phosphorus (P) content in lettuce leaves are presented in Figure 10, it was found a significant difference between the two systems at p<0.05, CD(0.05)=0.196. The highest value of P was achieved in the ACRz system than in the NCRz system. The increment in P content was 66.6%. In concern of potassium (K) content, it is clear from the results obtained in Figure 10a that the value of the K content of plants cultivated in the ACRz system is higher than its content in plants cultivated in the NCRz system. The increment was about 45%. Where the data found significant difference between the two systems at p<0.01, CD(0.01)=1.169.

Furthermore, the data on calcium (Ca) in Figure 10a revealed a higher percentage in the cultivated plants of the ACRz system. The increase in Ca values were 24.6%, and showed a significant difference at the (p < 0.05), CD(0.05) = 0.334. Also, Plants cultivated in the ACRz system significantly gave the highest content of Mg, in comparison to control (NCRz), the increment was about 75% as shown in Figure 10a. And the significant difference was at p<0.01, CD(0.01)=0.097. Besides, the data in Figure 10b reveals that Cu content in the plants of the ACRz system was higher than its concentration in the plants cultivated in the NCRz system. The augmentation in the concentration of Cu was 33.4%. The two systems were significantly different at p<0.01, CD(0.01)= 1.934. Also, the result showed that the increment of Fe concentration in plants of the ACRz system, was higher than in plants of the NCRz system, by an increment of 44.4%. It was a significantly different at p<0.01, CD(0.01) = 11.766. Mn concentration in the two systems showed a significant difference at p<0.05, CD(0.05)=42.332, where the concentration in the plants of the ACRz system was higher than in the NCRz system, by an increment of 54.9%. Likewise, the case of Zn concentration, showed a significant difference at p<0.05, CD(0.05)=49.549, where the higher concentration was in the ACRz system, by an increment of 58.6%.



a. N, P, K, Ca, Mg, and total phenol



b. Cu, Fe, Mn, and Zn.

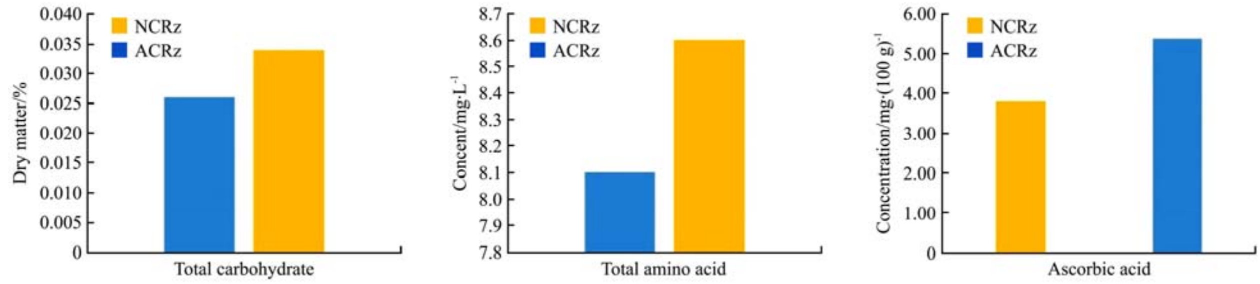
Figure 10 Effects of ACRz and NCRz systems on the non organic components

3.5.1 Total phenol content

The analyzed data in Figure 10a reveals that the NCRz system significantly increased total phenol by 66.76% compared to ACRz, the significant difference was at $p<0.01$, CD(0.01)=0.172.

3.6 Total carbohydrates, total amino acids, and ascorbic acid

The analyzed results of the total carbohydrate of lettuce leaves are depicted in Figure 11a. The results obtained reveal that the total carbohydrate content of the plants cultivated in the ACRz system was higher than the plants cultivated in the NCRz system, the increase in carbohydrate content was 30.7%. The statistical analysis of our obtained findings showed that the total carbohydrate content was significantly higher $p<0.01$) in the ACRz than NCRz. And this indicates the efficiency of our demonstrated system (ACRz). Concerning total amino acids, the findings in Figure 11b show a significant increase in total amino acids ($p<0.01$) where total amino acids of plants cultivated in the ACRz and NCRz systems were assessed by 8.6 mg/L and 8.1 mg/L, respectively, with an increment of 6.2 %. The result in Figure 11c demonstrated that the content of Ascorbic acid in the plants cultivated in ACRz was higher than the concentration in the NCRz systems, with an increment observed of 41.9%. The samples of plants from the two systems were significantly different at both $p<0.01$, CD(0.01)= 0.168.



a. Total carbohydrate content b. Total amino acid content c. Ascorbic acid

Figure 11 Effects of ACRz and NCRz systems on total carbohydrate and total amino acid of the plants cultivated

4 Discussion

Mainly, there are two outputs in this work: the first is to collect the temperature and humidity data automatically, displaying them as real-time monitoring on the Blynk smartphone application interface, and export them as an excel sheet as a weekly report. The second is even more important for automatic switching ON/OFF of cooling fans to monitor the temperatures on an automatic basis. Blynk application interface produces the output of temperature and humidity as well as the status of fans. In contrast, Dangi[27] presented a design and an application of an Arduino-based temperature sensor that was also utilized to measure humidity levels. The idea of this study was only to create a device based on an Arduino board for monitoring temperature and humidity, not to control them automatically such as in our study. Furthermore, Singhala et al.[28] studied an obscure temperature control system that was utterly simulation-based and no hardware application was performed. The system suggested was very uncomplicated and effective, but hardware implementation and investigation remain the work's future scope. In addition, Bhatia et al.[29] made a speed control technique based on temperature change, for adjusting temperature range, but it was not applied in real, it was depending on simulation software to design the hardware and simulate it on a computer.

Lettuce production was possible, even at particularly high air temperatures of up to 41°C, as long as their roots were cooled[18]. In this study, all plants were exposed to fluctuating tropical air temperatures while their root zones were maintained within two different ranges: 28.7°C-29.2°C (ACRz), and 29.5°C-31.5°C (NCRz).

The results revealed the significance of the proposed system ACRz to decrease the temperature inside the root zone. Shoot growth was greater under ACRz than NCRz. Higher shoot fresh weight could be attributed to higher root fresh weight since larger root systems improved nutrient and water uptake this agrees with, He et al.[30], where stated that, the total biomass of lettuce was higher in the cooled root zone than exposed to the ambient temperature. Although the lettuce in ACRz had higher leaves number, leaves width, shoot, and root length, dry weight of shoot and root than the lettuce cultivated in NCRz. This conferred no obvious benefits in terms of yield (i.e., shoot biomass) at NCRz but instead only at ACRz. These results agreed with the experiment results of Sakamoto and Suzuki[3], which revealed that leaf area, stem size, fresh weight, and water content of lettuce were achieved at root zone temperature between 25°C to 30°C.

Chlorophylls and carotenoids are considered essential components in the photosynthetic complex[31]. The result demonstrated that our systems ACRz, and NCRz have a significant difference in the chlorophyll content and carotenoid of leafy lettuce plants. The highest chlorophyll a, b, and total contents were obtained in plants cultivated in ACRz with cooling treatment. This reduction in photosynthesis pigments may be due to insufficient nutrient uptakes because of the shortage of the root systems as a result of unsuitable root zone temperature, this agrees with Nauš et al.[32] were, reported that the variation in chlorophyll content among the same species can result from the availability of mineral nutrition, environmental conditions, time of harvest, natural heterogeneity among species, and the difference in growth conditions, which may lead to a redistribution of chloroplasts within mesophyll cells. The result is also compatible with the results of Adebooye et al.[33], where the best result of chlorophyll content in that experiment was achieved when the root zone temperature lay between 25°C to 30°C. In addition, He et al.[30] stated that photosynthesis pigments were higher in the cooled root zone than the exposure to the ambient temperature which fluctuated between 23°C to 38°C.

Furthermore, for all the non-organic components (mineral nutrients) analyzed, the amounts absorbed by the plant increased in the ACRz. In contrast, the amount of mineral nutrient absorbed in NCRz was lower than in plants cultivated in ACRz. The general physiological explanation for our results is that in our ACRz system all the enzymatically mediated mechanisms with respect to minerals uptake were at their best. This agrees with Adebooye et al.[33] where reported that, the low level of minerals uptake may be associated with reduced root function which significantly limited solute uptake, and these may be linked with the reduction in photosynthesis pigments. Thus, reflect a reduction in plant morphology and productivity. Also increasing the roots' nutrients uptake may be due to the effect of the ventilation speed of the fan, whereas Lakhiar et al.[34] stated that atomizer droplet size is an essential parameter of the aeroponic system and can affect the nutrient mist collection efficiency and the depth of penetration of the nutrient spray. The plant root's mist collection efficiency depends on its filament size, drop size, and velocity. Where the velocity of the ventilation forces the nutrient solution droplets to stick to the roots hence, the plant roots can absorb more nutrients.

Also, Sago et al.[13] mentioned that the nutrients absorption volume, increased due to increased ventilation speed. The droplets' size becomes smaller because of evaporating the external layer of the droplets as a result of the ventilation speed. Therefore, the increased evaporation rate and hence root nutrients absorption rate as a result of existing high ventilation speed. Furthermore, root ion absorption can be regulated by the transpiration ion mass flow to roots[35]. Therefore, the dependence of root ion absorption on wind speed and root zone temperature was influenced by the ventilation speed and temperature dependence of root water absorption.

The production of several plant metabolites is influenced by root-zone temperature in many plants, including leaf vegetables[30,33,36,37]. This study's result showed that total phenol increased significantly in NCRz (control) as a result of an increase in the temperature inside the root, while the total phenol content was lower in the ACRz system. This may be due to exposing the roots to heat stress in NCRz because of the absence of cooling technique. For supporting this study's results, Sakamoto, and Suzuki[3] reported that exposure of roots of red lettuce to a temperature between (25°C-30˚C) did not alter the contents of phenols, and the high value of total phenol happened as a result of exposure the plant roots to low temperature (10°C). Also, Adebooye et al.[33] revealed that, in African snake tomato, raising the root-zone temperature increased the contents of phenols in the leaves. From the results, when the plant was exposed to not suitable conditions from temperature (high or low), the total phenol concentration increases in the plant to face the inappropriate conditions.

Moreover, the result demonstrated that the ascorbic acid achieved significantly higher concentration in the case of ACRz, while achieving a lower value in NCRz. This may be due to the absence of cooling in root chambers and there was heat stress in NCRz, while the presence of cooling the roots in ACRz. This result agrees with Hernández et al.[38], who found that the ascorbic acid concentration was significantly lower at a temperature of 32°C. and Besides, Adebooye et al.[33] found that the leaf ascorbic acid content was slightly increased by root exposure to low temperatures (25°C and 10°C), but this difference was not statistically significant compared to the higher temperature (30°C). This means that a temperature higher than 30°C poses heat stress for plants cause reducing the ascorbic acid content. Therefore, the importance of the ACRz system is demonstrated for cooling the root zone to the appropriate level.

The results of total carbohydrate and total amino acids revealed that the total carbohydrate content and total amino acids were significantly higher (p<0.01) in the ACRz than NCRz. The reduction in them may be due to sufficient plant exposure to heat stress in NCRz, which makes the increment of total amino acid and total carbohydrate values in ACRz significant. This also may be due to the good absorbance of nutrients and good photosynthesis operation as a result of cooling the root zone in ACRz system to the appropriate level. Our research reports for the first time the total amino acid and total carbohydrate of lettuce as influenced by root zone temperature and automatic cooling, Therefore, the findings of this study could not be compared with any previous study on this subject.

It can be said that our obtained findings indicate the efficiency of our demonstrated system (ACRz). The data collecting and real-time monitoring of temperature and humidity, and cooling of the root zone area to make it suitable for plant growth in the aeroponic system. Furthermore, these outputs show that smart monitoring and control in Aeroponic-based IoT technology and smart decisions according to temperature and humidity data need further studies to detect the potential of IoT technology in aeroponics and the effectiveness of smart monitoring and control.

5 Conclusions

In this study, an aeroponic system was designed and supplied with wireless sensors monitoring technique based on IoT technology. The system was designed and implemented to obtain data on temperature and humidity on a smartphone application and also obtained through a weekly report on a personal e-mail. This data was per hour throughout the period of cultivated plant (lettuce) production. In addition, the technology controls the temperature automatically through an Arduino board connected in a specific way with a cooling fan, when it reaches a certain limit, it turns on the cooling fan to reduce the temperature. This system with automatic cooling has proven an effective way to reduce temperature and stable the relative humidity inside the root zone chamber compared to the traditional aeroponics system. This new system significantly enhanced lettuce's absorbance of inorganic nutrients and other plant characteristics. The findings of this study revealed that automated cooled root zone system of this study increased the lettuce absorbance of non-organic nutrients such as N, P, and K by 45.5%, 66.6%, and 45%, respectively, also increased the fresh weight, total chlorophyll, ascorbic acid, total carbohydrate, and total amino acids increased by 131.0%, 26.2%, 41.9%, 30.7%, 6.2%, respectively in comparison with the conventional aeroponic system. The results of this research can be applied in commercial aeroponic systems to increase productivity with simply available possibilities (automated cooling fan), and decrease labor's work for getting the data of temperature and humidity because the data of the system could be received the smartphone.

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