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Soilless Indoor Farming: A Systematic Review of Iot-Based Monitoring Systems and Physiochemical Characterization Methods for *Lactuca Sativa*

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Abstract: With the emphasis of smarter, more efficient crop growing methodologies coupled with advances in sensors, Internet of Things (IoTs) and artificial illumination especially at the urban areas propel the development of indoor farming to another level as never been seen before as per compared to open and large-scale farming. However, there is a relatively big void in term of reference data availability for soilless indoor farming i.e precision farming, level of nutrients, light irradiances, yield improvement and etc. This review paper primarily aims to design and implement IoT system for real-time monitoring of multiple parameters in indoor farming. It involves using related sensors and components to monitor critical parameters in real-time. Edge computing solutions and a cloud-based storage/computing to be applied accordingly as tools to facilitate data monitoring and storage. The study includes the installation of various sensors such as nutrient quality monitoring (NPK sensors, pH, Electrical Conductivity (EC), nutrient temperature), climates monitoring (humidity, indoor room temperature, CO_2 gas) and irrigation (flow, level and turbidity). All of these data then shall be transmitted accordingly to relevant processors, monitoring system and then being stored at clouds. The methodology is structured in a way that the system could be scaled-up for larger space and modular setting. Nowadays, IoT system is used widely in farming but trending towards application in indoor farming, for example, soilless lettuce indoor farming. This review paper has illustrated the bio-characteristics of the lettuce: Lactuca Sativa such as morphological or physiological parameters and biochemical parameters like basic chemical composition, chlorophyll, micro/macro minerals and so on which the parameters can be obtained by using modern IoT system. To set up soilless lettuce indoor farming, modern IoT system is utilized and the overall process from data monitoring to data harvesting can be simplified.

Keywords—Biochemical Parameters, Carotenoid, Data storage, IoT Systems, Indoor Farming, Light source, Microcontrollers, Microprocessors, Micromineral, Physiological Parameters, Real Time Monitoring System, Systematic Reviews, Sensors, Total Phenol Content, Vitamin C, Wireless Sensor Network

I. Introduction

While large area and open space agriculture practices are very much common in the non-urban area, with the rapid migration to the cities and/or urban areas, the globe is experiencing unbalance development in term of food production while trying to sustain the livelihood of humanities in general. This created an upward pressure on the food supply chain on top of existing limited urban resources compounded with shrinking of arable land as well as exposure to political instability, geographic and limitation of manpower. Innovative agriculture practices could be very much key points to overcome the above challenges and limitations. Indoor farming coupled with the advances in technologies for example sensors and Internet-of-things (IOT) is a promising approach to overcome these challenges in term of land and water shortage, shrinking arable agricultural land due to various climates impacts, shortage of manpower as well as highly adoptable to be implemented in urban areas. Typically, urban areas are well connected to power source/electricity and internet connection are reliable and stable thus providing a good platform for indoor farming. As the rise of urbanization and the increasing population density in country, the space for farming or gardening become scarce and limited, thus indoor farming is an alternative way, not only adds aesthetic value but also purifies air [2].

In this trend, the Malaysia government have put some efforts on promoting it in terms of available technologies. It has been pulled out to discuss and aim to achieve by looking to its 12th Malaysia Development Plan. The strategies that taken by the government are research and development on quality of crops, collaboration with international parties to enhance the research skills and ensure food security and agri-food availability, and also implement digital technology into farming, production system and marketing. The effort from Malaysia Digital Economy Corporation (MDEC) to adopt IR 4.0 agriculture technology involving various smart farming activities, such as fertigation, irrigation and soil monitoring have proven successfully. For example, autoflo fertigation system from Autoflo Technology is designed to ensure every crops receive sufficient water and fertilizer [3]. The system also has sensors to collect data about the farm condition such as soil moisture, soil pH value and environmental parameters like temperature, then the owner can view the data via the Internet in everywhere. Furthermore, the drip irrigation for small scale farming is used to conserve more water by preventing water wastage and clogging problem because it delivers specific amount of water to the targeted area. Agriculture dripping for big scale farming emphasizes on advantages from

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commercialize crops, although huge investments in the beginning but can get return from exporting crops such as oil palm. There are some industrial participants involved in indoor farming such as Babylon Vertical Farm in Ampang Jaya which aim to minimize the water usage up to 90% from traditional farming, targeted to achieve the ambitions of eliminating hunger caused by the unfavorable farming and economic conditions. In addition, Sunrich Awesome Sdn Bhd in Sibu produced 3.5 tons of fresh vegetables per year in an indoor controlled-environment farm which free form using pesticides, herbicides and heavy metal [4].

In this paper will more focusing on indoor farming. Indoor farming refers to utilizing an indoor space or enclosure for farming with artificial lighting as photosynthesis sources. The method is similar concept by combining the design of farms and structures with several levels of growing beds [4]. It could be hydroponic-based or other soilless-based approaches and normally on fertigation or continuous pumping irrigation modes [5, 6]. Recent development of indoor farming were highly motivated with the advances in lighting or illumination sources and growing trend/demand in controlled environments for agricultural activities [7]. Literature compilation on studies and developments on this area mainly involved the adaptation of complex components and functionality such as artificial intelligent algorithms [8], various sensors and actuators [9-11], IoT components [12-14] and multi-spectral systems storage element [15-17] for monitoring [18, 19], precision farming [20], yield optimization [21, 22], automated control and detection applications [8, 9].

However, there is a noticeable void in term of literature on IoT based indoor farming related parameters particularly in Sarawak as most available references are mainly based on open space and large area farming. In addition, the adaptation, direct scaling and modularity of IoT solutions for real practical indoor farming is yet to be widely implemented or seen in indoor farming. This reason becomes the motivation to publish this review paper. To figure out the appropriate equipment for the smart indoor system for the user, there are the features of the electronic components in the following section be listed down to ease the selection.

The reasons why the indoor farming is not fully adopt include high operation cost, impractical for wide public, high energy consumption, and limited crop size that suit this farming method. In technical way, challenges for IoT implementation such as internet connectivity in certain places, security factor, reliability on sensors, technology selection and complexity, data analytic and visualization [23]. Therefore, these challenges need to be considered and seeking for the most appropriate way to overcome it.

Challenges and advantages in iot based indoor farming

The challenges when implementing IoT in indoor farming are discussed in this section. The challenges are internet connectivity, security factor, reliability, selection technology, data analytics and visualization.

Initially, internet connectivity is a concern when implement IoT in indoor farming. In some rural areas, wireless connectivity is weak or not applicable. It might because of the internet coverage area or the implementation budget from the government. If it is at a wide and big land, the energy source is one of the problems to supply energy to the wireless system, relates to the limited coverage area. Moreover, the internet can be affected by the building or trees nearby, it may leads to multipath propagation, eventually the wireless potential is unstable and cannot work consistently because the data collected is interrupted and may affect the whole system performance [23].

Next, one of the concerning points is security factor. Most of the smart system consist of online database which will store the sensed or processed data and personal information for the identification. Although there is data protection methods such as encryption, temporary identification, but these methods are applicable for static data. It is complicated for the agricultural sector database because it is frequently updated anytime. IoT system usually defenseless especially to environmental tempering likes attack by animals or thieves, targeted by device capture or DOS attacks. User usually prefer in cheaper to save cost but it is risky due to low security protection [23], data may leaks and leads to selling unnecessary products back to them or need to pay fee or charge by the other organization or government because of the collection and circulation of personal data issue [24].

Data can vary at any time and does not have a linear relationship with time, leading to potential reliability issues. The smart automation system relies on the data from the sensor for further data interpretation and takes action according to the algorithms. If there is the case that the sensed data is interrupted due to unforeseen circumstances such as signal blocking or environment parameters, it will cause system failure or proceed with incorrect action. This eventually makes the users have to handle huge loss of the crop harvesting and will affect the confidence of applying IoT system in agriculture by the users [24].

The component or technology used is varied according the requirement, so there is an issue of selection technology. There is diverse smart system which designed for different specific tasks, the selection also will vary according the necessity, there is no any universal IoT components but sure will have the most appropriate to be used. These selection criteria needs the basic understanding of knowledge so that the user can know the differences and figure out the familiar components [23].

Last but not least, after collecting data from the sensors, the user needs to do analysis based on them, therefore data analytics and visualization brings up here. The basic cycle of the smart system is to combine data from different sensors and provide a brief information through proper integration. There have different methodologies to do data integration and it is based on the computation needs, energy consumption and communication requirement. The data presenting way also important when dealing with big IoT data due to the structured, semi-structured and unstructured nature of it. Moreover, the cloud computing platforms enriched with GUI facilities such as ThingSpeak provides a good insights, it is one of the way for the users to have an easier data visualization and for further analysis [23].

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The advantages of implementing IoT in indoor farming are high crop harvesting efficiency, high energy and cost efficiency and guaranteed crop quality. First, through controlled environment by using IoT based smart indoor farming system result in high crop harvesting efficiency. The crops are grown in the controlled environment designed by the users and it is not affected by the outside weather conditions. In addition, indoor farming can provide more crop rotations annually than open field agriculture. It is because the crop cycles are faster due to controlled optimum growing parameters such as temperature, humidity and light which enhance the growth. This can provide consistent and reliable growing cycles to meet specific customer demands such as year-round availability of fresh produce and customized crop varieties [4].

Next is high energy and cost efficiency. Due to using artificial lighting such as high efficiency LED lighting ensures minimum power use for maximum plant growth. The lighting parameters such as photosynthetic wavelength can be controlled by using computer which suitable for the plant growth, so can minimize energy while optimizing crop yields. The smart system with wireless capability can inform the users regarding the crop information through SMS text messaging or mobile app notifications and would require labor only for on-site planting, harvesting and packaging [4].

Last is ensuring guaranteed crop quality. The crops thrive in a precisely controlled indoor farming environment where factors like air quality, water purity and light intensity are optimized for maximum growth and quality. All of the environment parameters such as air, water, light, nutrient quality can be measured and detected by the respective sensors installed in the automatic smart system, and then the users can adjust them through changing the optimum value. With the proper actions, the crops can grow faster but with high quality, this can saves time and maximize the profit earned [4].

Design Process Block Diagram

The place or site is enclosed or indoor space, which assume that it will not receive any natural sunlight, so it is important to have the artificial lighting available in the particular place for the photosynthesis purpose. Artificial lighting be used usually is LED or fluorescent lamp, depending on the power consumption and the indoor farming scale. Either it is soil-based or hydroponics-based, the crop needs water as well. It cannot be only pure water, but with some mineral solution inside which the necessary mineral ions can promote the crop growth. Surrounding temperature also one of the concerning factor because the optimum temperature between (25-30℃) enhance the plant elongation, if below 25℃ or above 30℃ for a long time, it will inhibit the plant elongation but not affecting stem thickness [25]. Next, the air circulation within the indoor space is crucial so that the space will always have fresh air flowing. It is suggested that the site should have the ventilation to ensure flowing air. Last but not least, the crops selection for the hydroponic is recommended using herbs or green plants such as tomato, lettuce, pepper and etc. Figure 1 shows the basic concept of the indoor farming design model and the factors that should take note.

Figure 1: Indoor Farming Design Model

II. Materials and Components

Before we find the necessary materials, we need to know every particular stage of a smart indoor farming system. A smart indoor system consists of 6 stages which are site selection, crop selection, irrigation system, light sourcing system, wireless monitoring system and real-time supervision anytime and anywhere. In this section, we will more emphasized on the components or software used in smart irrigation system, wireless monitoring system and real-time supervision. Figure 2 shows the working operations for a whole smart IoT based indoor farming and the working layers have distributed into 3 layers which is sensing layer, internet layer and user interface layer.

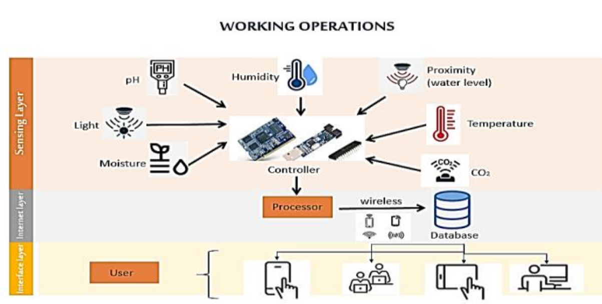

Figure 2: Working Operations of IoT Based Smart Indoor Farming

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Sensors

First and foremost, the sensors play an important role in whole smart indoor farming system, they collect the respective data or parameters and the data will be processed through the microcontroller and deliver the data through wireless channel to the online server so that the user can access the data in wireless manner anytime and ease further interpretation. The sensors usually be applied on the irrigation system and dependent on the user's requirement. As more sensors be used, higher accuracy for the microcontroller to process the received data and proceed to the irrigation process.

Moisture Sensors

From the research, most of the system use soil moisture sensors as one of the sensors. This is important because sufficient amount of water is one of the requirements for the plant growth. The soil moisture sensors have two types; resistive and capacitive. The researcher [26] did mentioned using the resistive-typed sensors are whereas these researchers [27-29] used the capacitive-typed sensors. Based on the research, some of the researchers mentioned about the actual type and model of the soil moisture sensors such as YL69, EN13637, FC28, EC20EC5 and 10HS serve as the purpose in smart irrigation system. Table I shows the characteristics of each kind of moisture sensor and respective research source. Although there are many researchers did not mention the moisture sensor type but we can see that this sensor plays an important role, thus it appears in most of the smart indoor farming system.

Temperature Sensors

Next, temperature sensor is used in the smart farming system. It is important because optimum temperature is beneficial for the plant growth. The plant or crop cannot survive in the soil either too hot or too cold. Based on the research, the type of the temperature sensors are used are SHT75, PT100, SHT30, LM35, DHT22, DS18B20 and DHT11. Table II shows the different types of the temperature sensors, respective features and references.

Table I Different Soil Moisture Sensors With Respective Features

Sensors	References	Features
Capacitive (analog)	[27-29]	Voltage range: 1.2V to 3V Safe material-long lifespan Output ADC: 230 to 600
YL69 (digital/ analog, resistive)	[1, 30-32]	Good surface planarity Good oxidation resistance
SEN13637 (analog, resistive)	[33]	Good corrosion-resistant Long lifespan
FC28 (digital/ analog, resistive)	[34-36]	Voltage range: 0-4.2V Greater precision, by measuring the dielectric of the soil content
ECH20EC5 (analog, resistive)	[37]	Higher volumetric water content accuracy Low maximum measurement volume
10HS (analog, resistive)	[38, 39]	Voltage range: 3-15V to 0.3-1.25V Better volumetric water content accuracy High maximum measurement volume

Ultrasonic Sensors HCSR04

Next, another parameter is water level in the container. To measure the water level, most of the researchers use the ultrasonic sensor, HCSR04. The modified system will be installed on top of the container and the sensor is located above the water surface. Its effective range is 2cm to 4m and the maximum operating voltage is 5V. The ultrasonic sensor, known for its cost-effectiveness and low power consumption, digitally collects data on water levels, ensuring precise irrigation control and system efficiency [28, 62-66].

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Table II Different Temperature Sensors With Respective Features

Sensors	References	Features
SHT75 (digital, capacitive)	[26]	Big band-gap sensor measure temperature (-40-120℃) Low power consumption
SHT30 (digital)	[40]	High temperature and humidity accuracy within ±0.1℃ and ±1.5% Low cost and low power consumption compared to DHT22
LM35 (analog)	[31, 41, 42]	Wide temperature range Low cost, no need ADC. More accurate and effective than thermistor and thermocouple
DHT22 (digital)	[28, 35, 36, 43-45]	Low cost and low power consumption More accurate than DHT11 Limited operating voltage High temperature and humidity accuracy within ±0.5℃ and ±0.5%
DS18B20 (digital)	[28, 29, 33, 37, 46-48]	Low cost, high precision, waterproof Wide temperature range: -55 to 125℃ (accuracy±0.5℃)
DHT11 (digital)	[2, 13, 29-32, 34, 49-62]	Temperature range: -55 to 125℃ with accuracy ±5℃ Limited operating voltage Have ADC, connect to microprocessor

pH Sensors

Then, pH sensor is applicable in the smart farming system. It depends on the setup and condition of the environment and also the requirement of the user. For instance, the researcher [50] apply pH sensor in his proposed system to measure the pH value of the soil and provide suggestion to employ it in huge farming sector. Based on indoor farming matter, if the user able to do irrigation daily, then water storage tank for the crop is not necessary. In the contrary, the user is encouraged to proceed to the hydroponic system to enable the irrigation process. The optimum pH value of the water for the plant is between 6.5 and 7 [46]. If it is solution mixed with ions, the pH value will be slightly decrease, for example, the solution mixed with hydrogen ions, the pH value is around 5.5 to 6.5 [67]. There is another way to measure the condition of the solution which refer to the parameter electrical conductivity. Based on the research [39, 46, 67, 68], the total dissolved salt in the solution will affect the ability of the plant to absorb water, so we need the sensors to ensure the optimum salinity of solution which is around 1.5-2.5ds/m. Table III summarizes the specifications of the sensors, total dissolved salt (TDS) sensor and ES-2 sensor.

Table III Different Ph Sensors With Respective Features

Characteristics	TDS sensor (analog)	ES-2 sensor (digital)
Input voltage	3.3-5.5	3.6-15
Output voltage	0-2.3	3.7-5
Working current	3m-6m	0.5m
Range	0-1000ppm	0-120ds/m (in range -40 to 50℃)
Accuracy	±10% full scale	±0.01ds/m (±0.1℃)

Light Sensors

In this paper, although the focus point based on indoor farming but it can be allocated in the space with or without sunlight. If there is no any sunlight, we need to use LED as the light source for the plant. To measure the light intensity, light sensor such as SI1145 [57], SM206 [50] or light dependent resistor(LDR) [63] is needed. Besides that, the researchers [66, 68] also used light sensor in their proposed system. Table IV shows the specification of the mentioned sensors.

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Light Sources

In smart indoor farming sector, the light sources can be the sunlight or the artificial light such as Light Emitting Diode (LED), fluorescent lamps and etc. The researchers [55, 67] used LED as the light source for their proposed irrigation system. The LED light intensity can be controlled by the system by connecting it with the resistors and the resistors are used to limit the current flow throughout the circuit. Ildar [50] used LED as the light source and limit the light intensity to 2700 lux for the grown crop which is during germination period then do analysis regarding the effect caused by changing the environment parameters. According to the research paper [69], the authors proposed two kinds of light source, LED and fluorescent lamps for the lettuce growing environment. Both of them also have 2 different measurements, neutral-white (4000K,4100K) and daylight (5000K,6500K) and study the amount produced of the different spectral quality such as ultraviolet ray(340-400nm), blue (400-500nm), green (500-600nm), red (600-700nm) and far-red (700-800nm) and found that green ray light intensity is the most be produced. Through the observation, it is concluded as green ray produced is beneficial for the plant growth and amount produced by the LED is more than fluorescent lamp, besides that, the light source is encouraged to be as pure white as possible. It is believed that green ray can penetrate through green leaves easily and promote the photosynthesis process. The position of the light source also important. According to the research [70], the author suggest the ideal distance is 12 to 24 inches above the crop to prevent the crops be burnt and also recommended not to turn on the light source for whole time because the crops need at least 6 hours of "resting".

Microprocessor

For this application, the microcontroller and microprocessor become the central part of the system. Microcontroller that can be used in the system such as Arduino Uno, Arduino Nano and Arduino Yun whereas microprocessor such as Raspberry Pi, ESP8266, ESP32, MTS420 and STM32L152RE. The function is to ensure the operation among the sensors and the actuators accurate and precise, so that it can ease the whole farming process. Table V shows the characteristics of the controllers and the table can be used as a reference when choosing the appropriate controller for different usages and applications

Table IV Different Light Sensors With Respective Features

Specifications	SI1145 (digital)	SM206 (digital)	LDR (analog)
Operating voltage	1.7-3.6	4	12 (steady DC voltage)
Operating current	5.6m	2	5m
Temperature range	-40-+85℃	-65-+125℃	-25-+75℃
Proximity range	15cm-50cm	-	-
Illumination	1-128klx	-	10-100lx

Microcontroller

Microcontroller plays a vital role in a smart automation system. It serves as the brain of the whole system and controls the digital connection and interaction between the components, ensuring they can be functioned according to respective command or data [71]. Most of the researchers deploy the Arduino Uno as their main microcontroller in their proposed system as summarized in Table VI. It is because it saves budget, low power consumption, user-friendly, have 14 digital ports which are a 16MHz ceramic resonator and embedded 10-bit 6-channel ADC converter [54]. It is based on the ATMega328 microchip which provide the availability of writing the software on the board [49]. It can be programmed by using Arduino language which is merely a set of C/C++ that can be called from the code such as Arduino IDE. It takes the sensor analogue data, process it to digital data according the coding algorithm to command the actuators [62]. To send the data to the cloud, it needs to send to the microprocessor by using serial communication (RS232 serial data bus) [28], same goes to the case when it needs to retrieved the data from the cloud [31] because it does not microchip that can access in wireless medium. There are other types of Arduino board which is Arduino Yun and Arduino Nano [61], most of the specifications are similar, but in terms of wireless adaptability, Arduino Yun is convenient as it has Atheros AR9331 with Ethernet and Wifi ports [34, 36].

Table V Different Microprocessor With Respective Features

Micro processor	**Raspberry Pi**	**ESP8266**	**ESP32**	**IRIS-W10**	**STM32L152RE**
Processing chip	Broadcom system- 700 MHz CPU and VideoCore IV GPU	Espessif system - Tensilica L 106 RISC CPU, NodeMCU-12E Tool with SoC(system on chip), built-in WIFI module	Built-in wifi module	-	-
Ports	Video and audio (I/O), 4 USB(antenna),	USB port (Antenna, cloud-arduino)	12-bit ADC, DAC,34 GPIO, up to	64 GPIO, 16-bit ADC,10-bit DAC	116 GPIO 12-bit ADC,12-

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	40 GPIO	17GPIO, ADC(1-10bit)	18 analog sensor		bit DAC
Network protocol	Basic -I2C,SPI and Modbus Advanced - MQTT	1Pv4,TCP/UDP/HTTP 802.1b/g/n(HT20)	TCP/IP and full 802.11 b/g/n Wi-Fi MAC	802.15.4 low-rate wireless networks	-
Frequency band	64 bit core- run at (1.4,2.4,5)GHz, Bluetooth, Run open-source software	32-bit core- run at 2.4G-2.5GHz, Bluetooth	2.4GHz TRX , Bluetooth (4Mbps)	Wi-Fi 6, Bluetooth Low Energy 5.3 (2.4 – 2.5GHz)	Bluetooth
Machine learning language	Python, C++, Java, KNN	Python	-	-	-
Coding	Matlab, Linux, Android Studio	Arduino IDE Firmware: cloud, Linux, Docker Image	-	-	-
Operating range	Voltage: 3.3V, 5V	Voltage: 2.5-3.6V Input:3.3V,500mA Temp:-40-125℃	Voltage:2.3-3.6V Current:0.5A Temp: -40-125℃	Voltage: 1.8/3.3V temp: -40-85℃	Voltage:1.8-3.6V Current: 0.1mA-standby Temp: -40-105℃
Operating power	-	TX power: 802.11 b:+20dBm RX power: 802.11 b:- 91dBm(11Mbps)	TX: 802.11b. 20.5dBm RX:802.11n. 18dBm	TX :802.11 b:+17dBm RX sens: 802.11 b:- 87dBm(11Mbps)	-
Advantages	Credit-card sized, low cost, low power consumption, high clock speed	Secured security High clock speed Low maintenance cost than raspberry, small size, less power consumption	Ultra-low power consumption -deep sleep mode High clock speed	High clock speed Power effcient	Low power consumption
References	[30, 33, 35, 38, 41, 45, 50, 51, 55, 63, 66, 67, 72, 73]	[13, 28-32, 35, 37, 38, 44, 49, 54, 58, 60, 62, 64, 74-76]	[29, 40, 46, 57, 59, 71, 77, 78]	[23, 79]	[47]

Table VI Different Microcontroller With Respective Features

Arduino	Arduino Uno	Arduino Yun	Arduino Nano
Microcontroller	ATMega328	ATMega32u4	ATMega328p
Operating Voltage	5V	5V	5V
Input Voltage	7-12V	6-20V	7-15
DC current	50mA	50mA	50mA
Flash Memory	32kB(0.5Kb-bootloader)	32kB(4kB-bootloader)	32kB(2kB-bootloader)
RAM,ROM	2kB,1kB	2.5kB,1kB	2kB,1kB
Clock speed	16MHz	16MHz	16MHz
Digital + Analog pin	14+6	14+6	20+8
PWM output	6	7	6

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Serial communication	I2C,SPI	-	UART,I2C,SPI
References	[1, 2, 28-31, 35, 37, 38, 49, 52-54, 60, 62, 64, 71, 72, 75, 76, 80]	[34, 36, 81]	[61, 82]

Wireless Standard Communications

Wifi

Wifi is a wireless local area network technology based on the standard IEEE 802.11, it can operate in 2.4GHz and 5GHz frequency bands. It is extensively utilizing wireless technology available in portable devices such as tablets, smartphones, laptops and desktops. It is generally intended for internet access, offering wide bandwidth range, low power consumption and high transmission rate for long distance communication. It has an effective coverage distance of about 20m and 100m in indoor and outdoor environments respectively [83]. Antenna technology can be included to enhance the coverage area and allow to access in the further place. For other applications in agriculture sector, Wifi is commonly utilized for wireless sensing, video surveillance and communication in remote areas [71]. In precision agriculture application, Wifi extends diverse architectures by connecting several types of devices via an ad hoc network.

Bluetooth and BLE

Bluetooth or Bluetooth Low Energy (BLE) are a wireless technology that allows data and voice to be transmitted over short distances. It operates in standard IEEE 802.15.1, in 2.4GHz frequency band, the latest technology which enable it has a data transfer rate up to 50Mbps. Bluetooth is utilized to establish the communication link between devices over a short distance up to 10m [71, 83]. Because of operating in global frequency band, highly resistant to interference, low energy consumption and wide availability, it is suitable for wide range of devices and be employed in different agriculture application such as environmental monitoring and intelligent irrigation. In addition, BLE technology enable data communication at a very low power consumption [71, 83]. Mahesh et al. [77] proposed their irrigation system by using Bluetooth technology as their backup plan to receive the data in case the other connectivity is not functioning.

Zigbee

Zigbee is a wireless protocol based on the standard 802.15.4, operating in global frequency band 2.4GHz with a transmission rate up to 250kbps, which suitable for the small size farming [84]. Zigbee is also one of the best candidates among the wireless protocol because its low duty cycle, low cost, low power consumption, low latency and easy deployment. Based on this technology, the sensor nodes in the system can communicate with each other over a long range (i.e., 100m), it also can reduce the communication distance up to 30m for indoor situation [83]. For instance, Zigbee is also used to study the effect of signal strength on node spacing, base station and antenna height. Low power consumption because it can switch between active and sleep states to preserve the energy, so battery lifetime of sensor nodes can be extended. The authors [26, 41, 42, 51-53, 56, 85] deployed this technology in their automated irrigation system, it saves budget and also their easy integration capabilities into IoT applications through Zigbee gateway. It is endowed with stack MAC layer which gives basic security services, thus, allows one to have the access control and the use of an encrypted communication [26].

LoRa

Lora, the abbreviation of long-range radio, is a wireless protocol with different standards in China, the USA, the EU, and the Japan. It operates in frequency band range from 433MHz to 915MHz with a transmission rate of 10kbps [84]. The basic network architecture of a LoRaWAN consists of LoRa end devices, LoRa gateways and a LoRa network server. LoRa end devices act as the communication device, LoRa gateways act as a bidirectional communication or protocol adapter with the LoRa network server. LoRa network server takes the responsibility to process the data from and to the device [83]. The advantages of this technology is long-range transmission, low power consumption, low cost, eventually reduce device cost and flexible deployment. LoRa offers a bidirectional solution that matches machine-to-machine (M2M), WiFi or cellular technologies. LoRa presents a cost-effective method for linking batteries or mobile devices to the network or to end devices [83]. Andre et al. [40] proposed that install RFM95W radio transceiver in irrigation system to enhance its coverage area up to 2km but still able to lower the power consumption by switching it to sleep mode that allows it takes 70mA to run the system. The researchers [27, 37, 40, 57, 61, 71] utilized LoRa technology in their proposed irrigation system as their main wireless protocol. In this research paper [71] , the authors state that the reasons why utilizes LoRa technology instead of GPRS or Zigbee is because GPRS indulge more prices from the carrier provider and Zigbee is outdated for current situation.

GPRS

General Packet Radio Service (GPRS) is the packet data service for GSM-based communication and can support Point-to-Point Protocol (PPP). GPRS experiences delays and throughputs, such technology depends on the consumers that share the same communication channels and resources [83]. If the system scale is small, then GPRS protocol is appropriate as it provides high data transfer rate up to 171kbps between the devices. Using packet switching mechanisms, the data are transmitted from different sensors to a remote location across different channels and allowed for further analysis by using portable devices such as tables and mobile phones [33]. GPRS also facilitate the usage of Internet applications over mobile networks. GPRS is more established than

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other technology such as 3G/4G in some way if the place is entirely indoor or countryside which the 3G/4G is weaker in access the devices. It is low power consumption if comparing with other methods when deploying in the small scale indoor farming although coverage area is small and data rate is slower but it is just enough [39]. Santhana et al. [53] proposed this technology in their smart irrigation system which powered by solar and do analysis using fuzzy logic analysis. Srishti [1] proposed it in her irrigation system through using SIM900A modem and access data through online. Mahesh et al. [77] proposed this technology in their irrigation system besides using cloud and Bluetooth connectivity to make sure they still can acquire data in case one of the connectivity lost. Not only can used SIM900A modem, but also SIM800L which be proposed in [28, 48], it provides access to GSM/GPRS/850/900/1800/1900MHz network services for serving calls, SMS messages and exchanging digital GPRS data and also compatible with 3.3V and 5V.

Data Storage

In the whole smart indoor system, the sensors are assigned to collect data from the studied area and transfer it to the microcontroller for processing the sensed data. These processed data will be transfer to the cloud through wireless medium and also the microcontroller can retrieve data from it to actuate the device and undergo the particular processes. Cloud technology widely used in agricultural sector especially in the irrigation-based. Cloud storage is opened for storing, processing, accessing and retrieving data. Depends on its availability, some is free to public but also have paid option and convenient for the users to access in using varied devices or platforms anywhere. It assists in improving working efficiency such as saving time and also can help us to mitigate various risk and hazards because the cloud technology has the ability to generate alerts and notifications. Various types of online databases include MySQL, ThingSpeak, Thinger.io, Google Firebase, flask and The Things Network. In this review paper, we would like to present you the differences of these database so you able to choose the type that is appropriate for your proposed system.

Cloud storage is very well known in terms of technological area. It will not consume your physical working space and can access anytime and anywhere, quite convenient for the users for monitoring and further analysis purposes. One of the examples is Amazon Web Services (AWS). It has the free version but also paid option to have the additional features. The registered users can keep the data in this online storage and share to the specific users or among the systems and actuators for them to do the tasks assigned. This online software is applicable in both Linux and Windows OS and the supported machine learning language are HTML, CSS, JAVA, PYTHON and Node.js. The designed system can use MQTT protocol to communicate and share data to and from AWS cloud [27, 74]. It is secure in data collection and only can access through specific API gateway and either collected data or analyzed data can be viewed in graphical methods such as in graphs or pie charts to easily observe the data relationship [88].

ThingSpeak is one of the server platforms which is open-source for IoT application. The data that collected by the sensors can be transfer to this platform through microcontroller such as Arduino and Raspberry Pi as storage through wireless protocol such as HTTP protocol [86]. The type of the data can be categorized as eight fields including humidity, temperature, soil moisture, water flow and experiment site [35]. When the users want to extract the data from this platform, the users need to use API code to access the website, thus it is also secured [13]. It is also user-friendly as the algorithms are simple and easy to do analysis as ThingSpeak have the ability to implement the data and present it using graphical way.

Table VII Different Wireless Medium With Respective Features

Wireless medium		**Wifi**	**Bluetooth**	**BLE**	**Zigbee**	**Lora**	**GPRS**	**Sig-fox**
Standard		IEEE 802.11a,b,g,n	IEEE 802.15.1	IEEE 802.15.1	IEEE 802.15.4	IEEE 802.15.4g	N/A	IEEE 802.15.4g
Data rate(bps)		150M	1-3M	1M	250k	110k-250k	170k	100
Operating frequency		2.4GHz	2.4GHz	2.4GHz	2.4GHz	0.868-0.915GHz	900-1800MHz	0.868-0.915GHz
Number of RF channel		11	79	40	1,10,16	8,10	124	360
Channel bandwidth		22MHz	1MHz	1MHz	2MHz	500kHz	200kHz	100kHz
Cover range (m)		1-100	10-100	10	10-100	2000-15000	10000	10000
Network size		32	7	Limited by application	65540	15000	1000	1M
Power consumption (in TX	In TX mode	High-835mW	Medium-215mW	Ultra low-10mW	Low 36.9mW	Low-100mW	Medium-560mW	Low-122mW

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mode)							
Security	128bit AES	128bit AES	128bit AES	128bit AES	128bit AES	GEA,MSSG SN,MS-host	N/A
Topologies	Point-to-hub	Scatternet	Star-bus	P2P,star,mesh,tree	Star-of-star	Cellular	Star
Cost	Low	Low	Low	High	Low	Medium	Low
Limitations	High power consumption, long access time(13.74s)	Short communication range	Short communication range	line-of-sight of nodes between the sensor and the coordinator must be available	Limited network size, data rate, and message capacity	Power consumption problem	Low data rate
References	[2, 13, 27-31, 43, 46, 48, 49, 56, 57, 62, 66, 68, 71, 74, 86]	[1, 47, 77]	[33, 40, 44, 55, 74, 87]	[26, 41, 42, 51-53, 56, 85]	[27, 37, 40, 57, 61, 71]	[1, 51-53, 77]	[39]

The data can be visualized through using Matlab. This platform has the ability to sending alerts and notifications through SMS or Gmail according to the setup so the user can monitor the system anytime and anywhere [60]. MySQL is also an open-source online database based on Structured Query Language (SQL). It works on multiple platforms including Linux, Unix and Windows. Although it can be used, but mostly is associated with web-based applications and online publishing [35].

Thinger.io is an open-source online platform. It has both free and paid option depends on the user's requirement. In the research paper [44], the author use thinger.io platform as the data storage for the proposed system. The author mentioned that it is user-friendly because not only easy to use, but also the data can be visualized into different style such as donut chart, progress bar, serial chart and even can include the map about the location of the system. Besides that, it is inbuilt security provided by using Transport Layer Security (TLS) and Secure Socket Layer (SSL) cryptographic protocols to secure your data. It can be disabled just by sousing simple commands. The author connects the sensors with the microcontroller and send the data via MQTT protocol and connect to the Thinger.io platform. The data inside this platform can be viewed anytime and anywhere because it has online webpage and mobile app.

Google Firebase is a mobile and web app development platform owned by Google. It is built on Google infrastructure and scales automatically. It is user-friendly because it gives functionalities such as analytics, databases, messaging, reporting and easy to integrate with iOS, Android and the web for control purpose. API are packaged into single SDK hence it can be expanded to more platforms [65]. It is open-source so is cost effective and also secured only for the registered user email can access. The system can send the data including image to this database and the user can retrieve data anywhere. Data can be visualized in graphical way such as the picture and the graph and it provides a real-time database and backend service [32]. The user will be informed through the notifications from this platform and monitor the system anytime and able to edit the data through mobile application [59].

Flask is a graphical web interface and a mobile application which are implemented for the user to monitor the data in real time. In the research paper [33], the author choose this platform is because it is the most widely accepted web server for development purposes and offer better community support. It also offers a wide range of features like load balancing, fault tolerance and auto-indexing and compatible with the other web servers. The data can be transfer to this platform via wireless medium and the user can monitor the data in real-time through web application. The user will have a weekly graph report which summarize the particular location by showing the Google map and the data presented in tabular or plot form. It provides the ability to control the system to the user through mobile application. In short, it is considered as a micro-framework that embedded development server and fast debugger.

The Things Network (TTN) is an online platform which provide free and paid options for the user's requirement. It is a powerful database and mainly contribute to the devices which connected with LoRaWAN. It is secured also so that only the registered user can access the data. The associated app such as Datacake is one of the features implemented in this online platform. The user can transfer the data to TTN and TTN can process the data in a graphical way such as graphs and location map to ease for the further analysis. The user can monitor the data in real-time and able to receive the notifications or alerts from this platform via SMS and email. The researchers [37] proposed to use this platform as the data storage for the irrigation system and do the further interpretation regarding the fault detection in wireless sensor network (WSN) using Kalman filter.

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Table VIII Different Data Storage With Respective Features

Database	**MySQL**	**ThingSpeak**	**Thinger.io**	**Google Firebase**	**Flask**	**The Things Network**
Coding Language	HTML5,Javascriprt, PHP	python, JavaScript and MATLAB programming languages	Arduino IDE-include library file	Arduino Studio/ Arduino IDE-include library file	HTML, CSS, JavaScript	-
Cost	Free	Free	Free and paid	Free	Free	Free and paid
Presentation of Data	-	Data : graph	Data: chart, graph, progress bar, map	Data (real-time): graph, image	Data (real-time): graph, map	Data (real-time): graph map
Accessing method	Linux, Unix, Windows	PHP-data from API database JSON-data in android device	Webpage and mobile application	Webpage and mobile application	Webpage and mobile application	Web-page
Network security	Not secured	Secured	Secured (TLS,SSL)	Secured	-	Secured
References	[28, 39, 52, 71]	[1, 13, 31, 32, 35, 36, 48, 54, 60, 68, 86]	[44]	[29, 32, 59, 61, 65]	[33]	[37]

Case Studies

Case Study 1

According to the paper entitled "Smart-technologies in Irrigation Management of a Remote Land Plot", written by Matukhina et al., an autonomous system should have the ability to monitor and take action according to different situations. This is to enhance the convenience of the users by just informing the users through SMS or notifications so that the users no need to supervise the particular plot area whole time but still able to get the latest updates. To make the irrigation system smarter, the authors deploy the sensors such as moisture and temperature sensors to track the surrounding parameters in real time and also install an ultrasonic sensors at the water tank to monitor the water level. The actions are driven by the crop's need for sufficient water, influenced by factors like weather. Therefore, it cannot set the fixed timing to do the irrigation process but according the needs for instance when that day is a rainy day, the irrigation system does not need to carry on task frequently and vice-versa. The data from the sensors and the actions from the actuators will be sent to the online database so the users can access it anywhere and anytime through mobile devices [28].

Case Study 2

According to the paper entitled "Adoption of the Internet of Things (IoT) in Agriculture and Smart Farming towards Urban Greening: A Review", written by Madushanki et al, the authors have reviewed about 60 articles to compare the IoT specifications which can be deployed in the farming or agriculture sector. The authors introduce the functionality of the smart system and how IoT is used to achieve user goals. Compared to the conventional methods, the smart system can save more time and labor force, eventually increase the efficiency of crop harvesting. The authors found that Industry 4.0 in agriculture focuses on IoT aspects transforming the production capabilities including the agricultural domain, which considered soil quality, irrigation levels, weather, the presence of insects and pests as sensor data [89]. They also identified most of the utilization of the IoT are in the agriculture sector compared to farming sector. In addition, from the result of the research done by the authors, we can observe that the water management is the most crucial part that be emphasized in agriculture sector. Although water source is long lasting, but only the clean water is suitable for crop growth, therefore, with a proper development of the IoT in irrigation system, the water can be used wisely and efficiently. Furthermore, the data that usually be taken into account for the water management are environment temperature, humidity and soil moisture. We also can see there is a big demand of Wifi and mobile technology in agriculture sector because of its wide availability and wide coverage area. However, the other technology also be used according to the scenario, for example, LoRa, Bluetooth and Wireless Sensor Network (WSN) are used in some developed country due to limited network speed.

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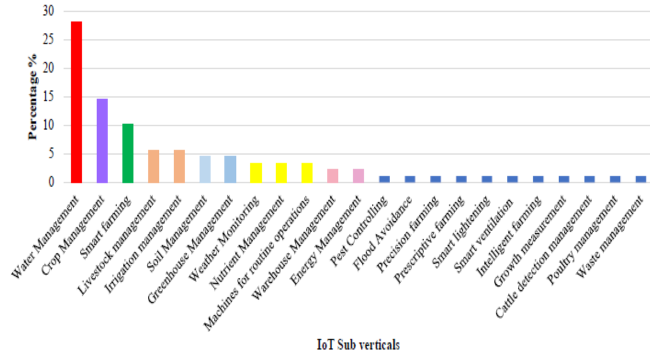

Figure 3: Different Sub Verticals In Agriculture and Farming Sectors, source from Figure 1 in [89]

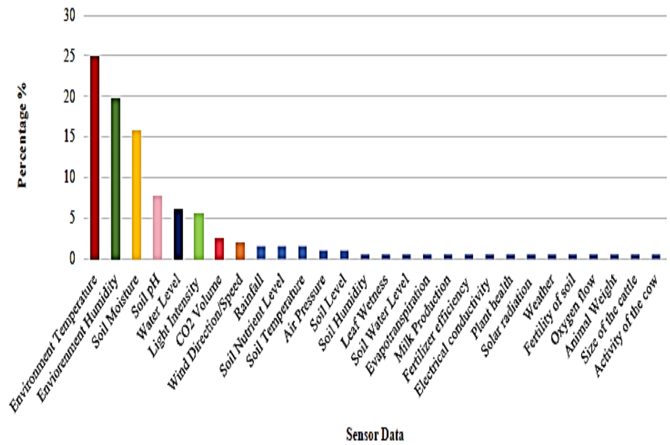

Figure 4: Utilization of Sensor Data In Different Categories, source from Figure 2 in [89]

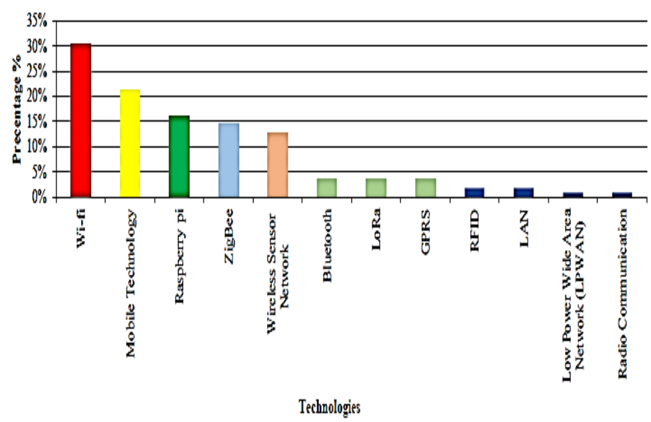

Figure 5: Overview of Different Technologies Used in the System, source from Figure 3 in [89]

Case Study 3

According to the research paper entitled "IoT based Smart Irrigation System", written by Srishti Rawal, the motivation for the author to develop a smart irrigation system is the importance of using water wisely in agricultural sector. In India, due to the rapid increasing population, the needs of food or agricultural products is increasing as well, same goes to the fresh water consumption which already recorded 83% total water consumption comes from the agriculture [1]. The author presents the idea through creating a smart irrigation system using IoT to control the amount of water supplied to the plot. The system consists of moisture sensors YL-69, microcontroller ATMEGA368P, GSM modem, and data will be stored in ThingSpeak database for processing. The author inserted two soil moisture sensors YL-69 in two different soil conditions, one is initial moisture level at 79% whereas the other one is over irrigated. From the result taken from 4pm to 5pm in this research, the moisture level to drop by 10% from over irrigated plot is taking longer period than the first plot. The result from the research paper is attached as table below and be sketched using graph to observe the reading. From this experiment, it is advised to ensure the correct operation of the water sprinkler to supply water to prevent over-irrigated case happen because if the crops usually in this situation, it may affect the root growth and eventually the crops died.

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Time (IST)	Sensor A(%)	Sensor B(%)
15:53:21	79	100
16:00:22	74	100
16:11:23	70	100
16:16:44	69	100
16:30:05	67	100
16:34:45	66	100
16:43:06	65	98
16:48:07	65	97
16:56:08	64	95
16:59:48	63	93
17:00:08	63	93
17:05:49	62	92

Figure 6: Result of soil moisture condition in two different soil condition within 1 hour, source from table 2 in [1]

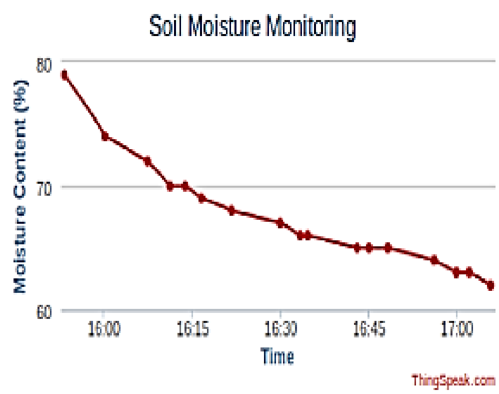

Figure 7: Graph of soil moisture condition measured by sensor A, source from Figure 5 in [1]

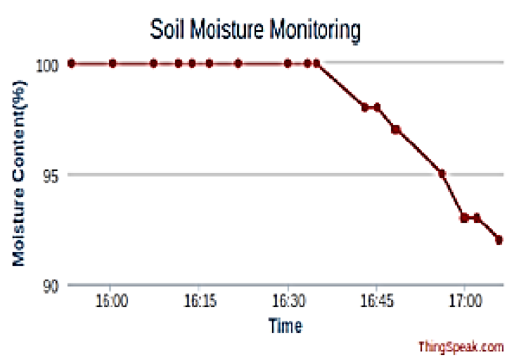

Figure 8: Graph of soil moisture condition measured by sensor B, source from Figure 6 in [1]

Case Study 4

According to the paper entitled "Design of a Smart Hydroponics Monitoring System using an ESP32 Microcontroller and the Internet of Things", written by A. Sneineh and A. Shabaneh, the motivation of the authors is enhancing the efficiency and performance of the hydroponics system through implementation of IoT. The reasons to implement IoT are because the sensor data can be collected in real time and it is quite accurate, user can change the environmental parameters based on the situations and easy to evaluate the system efficiency [46]. The proposed system consists of ESP32 microcontroller, total dissolved solids (TDS), temperature and pH sensors, and has the ability to integrate with online resources and mobile app such as Blynk IoT. We can observe that different kinds of the crops may have different parameters measurement. In this paper, the authors have chosen lettuce as the crop in their hydroponic system. They prepare three different tanks, first tank contains fresh water mixed with fertilizer solution, second tank contains the mixed potassium, phosphate and nitrogen solution and third tank contains phosphoric acid solution. The sensors are mounted in the basin and monitor the parameter changes. According to the result taken by them in 11 days, they have the stable measurement for parameters electrical conductivity (EC) and pH value except the surrounding temperature. Thus, they conclude that the optimum range of the parameters electrical conductivity and pH value is 1600-1800PPM and 6.5-7 respectively. Any value beyond the threshold value will prevent the crops absorbing nutrients, resulting in plant's death and crop loss [46]. Given that the experiment was conducted in Palestine with a constant average temperature, if the system is used in regions with fluctuating daily temperatures, incorporating a fan or heater can maintain an optimal temperature

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for plant growth. Once the TDS sensors detect that is lower water's salt concentration, it will trigger water pump and pump solution from the second tank. Once the pH value increases above the optimum value, the system will trigger the acid pump to lower down the pH value. The optimum measurements vary according to the crop selection as different crops have different nutritional needs when they compared their proposed work with the other.

Table IX Compared Parameters Among The Proposed System With The Other Work, Source From Table 3 In [46]

Controller Name	Average pH	Average water temperature (℃)	Average EC (ppm)	Communication technology
Arduino Mega 2560	6.60	32.28	1448.84	IoT,Wi-Fi
Arduino,Raspberry Pi3	7.50	31		IoT
Arduino,Raspberry Pi4	6.01	25.06	1344	Spectroscopic IoT sensor
ESP8266				NodeRed IoT,Wi-Fi
Arduino Uno,GSM Shield	6.11	29	1098.29	Wi-fi,xively server
Arduino Mega,ESP8266	6.2	28.9	1429	Ubidots Cloud
ESP32	6.8	26.55	1779	Blynk IoT apps,Wi-Fi,smartphone

Table X Ph Value, Electrical Conductivity (Ec) And Temperature Taken For 11 Days, Source From Table 1 In [46]

Day Parameter	pH	EC(ppm)	Temp. (℃)
Day 1	6.8	1780	20.5
Day 2	6.8	1778	20.5
Day 3	6.9	1781	21.0
Day 4	6.8	1778	21.5
Day 5	6.8	1779	22.0
Day 6	6.9	1777	21.5
Day 7	6.8	1782	20.4
Day 8	6.8	1778	20.5
Day 9	6.8	1778	20.9
Day 10	6.8	1782	20.8
Day 11	6.9	1777	21.2

Case Study 5

According to the paper entitled "A Wireless Sensors Architecture for Efficient Irrigation Water Management", written by Navarro et al. the motivation of the authors is to develop a cost-effective automated irrigation system in arid or semi-arid zones which the water source is important in daily life. Due to increased demand of water used in other sectors, it may suggest that the water resources for agriculture will be lower in both quantity and quality [39]. Relate to this reason, the automated irrigation system can be one solution because it will control the water supplement based on the necessary instead wastage of water resources. The authors select 4 experiment sites which at the South-East of Spain, sites are woody crop based, vegetable crop based, greenhouse soilless culture based and water reservoir. The authors have studied the power consumption factor of the system. The power consumption not just only based on the power rating of the electronic components that been used, it also based on the sample rate according to the user's requirement. Based on this research, the authors stated that the system will repeat in a loop cycle, which at the beginning, it needs time to do interface warm-up, acquire data from sensors and data storing for every 10min (sample rate set by the authors). After 1 hour, the data will share to the server through GPRS node, then the system return in standby mode until the next scheduled reading process. Aside the cycle, the authors studied the effect of the sample rate on the average power consumption. Logically, the higher the sample rate, more power needed for the system to operate, thus the higher the power consumption. However, when increasing sample rate, the amount of data shared is increased in less time. If the sample rate is reduced, the information will be available sooner but not power-efficient as few data be sent through GPRS connection. This has a greater effect in scenario which the farming scale and power consumption of the sensors are big but in the other words, this looks little importance for the overall system in a small scale.

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			Sample rate (min)					
			10	20	30	40	50	60
Woody crop	GPRS communication rate (h)	1	5.93	3.47	2.65	2.24	2.00	1.83
		2	5.73	3.27	2.45	2.04	1.79	1.63
		4	5.62	3.16	2.34	1.93	1.69	1.52
		8	5.57	3.11	2.29	1.88	1.64	1.47
		12	5.55	3.09	2.27	1.86	1.62	1.45
		24	5.54	3.08	2.26	1.85	1.60	1.44
Vegetable crop	GPRS communication rate (h)	1	2.06	1.54	1.36	1.28	1.22	1.19
		2	1.86	1.33	1.16	1.07	1.02	0.98
		4	1.75	1.23	1.05	0.97	0.91	0.88
		8	1.70	1.18	1.00	0.91	0.86	0.83
		12	1.68	1.16	0.98	0.90	0.84	0.81
		24	1.67	1.14	0.97	0.88	0.83	0.79
Greenhouse soilless culture	GPRS communication rate (h)	1	2.61	1.81	1.55	1.41	1.33	1.28
		2	2.41	1.61	1.34	1.21	1.13	1.07
		4	2.30	1.50	1.24	1.10	1.02	0.97
		8	2.25	1.45	1.18	1.05	0.97	0.92
		12	2.23	1.43	1.17	1.03	0.95	0.90
		24	2.22	1.42	1.15	1.02	0.94	0.88
Water reservoir	GPRS communication rate (h)	1	2.20	1.61	1.41	1.31	1.25	1.21
		2	1.99	1.40	1.20	1.10	1.04	1.00
		4	1.89	1.30	1.10	1.00	0.94	0.90
		8	1.84	1.24	1.05	0.95	0.89	0.85
		12	1.82	1.23	1.03	0.93	0.87	0.83
		24	1.80	1.21	1.01	0.91	0.85	0.81

Figure 9: The average power consumption in milli-Ampere(mA) for different sample rate and time for data sent through GPRS connection, source from table 4 in **[39]**

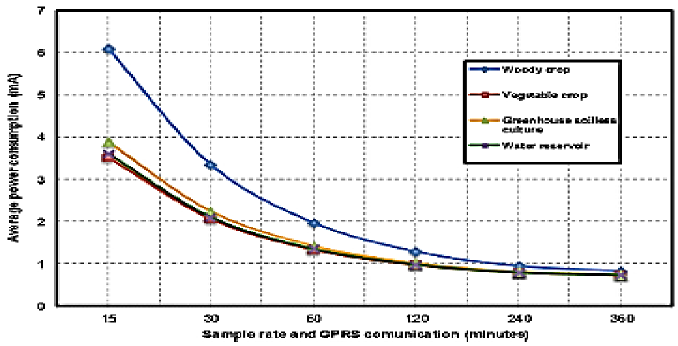

Figure 10: Graph of the average power consumption in milli-Ampere (mA) for different sample rate and time for data sent through GPRS connection, source from Figure 10 in **[39]**

Biochemical characterization techniques

Qualitative Analysis

Phytochemical screening tests can contribute to the discovery and development of drugs due to their ability to identify bioactive compounds [90]. According to Ahmed et al. [90], the authors employed these tests to determine the phytoconstituents, including flavonoids, alkaloids, glycosides, terpenoids, steroids, flavones, tannins, phenols, and saponins in the leaves of *Sagittaria trifolia*, except the alkaloids and terpenoids. Nonetheless, phytochemical screening tests confirmed the presence of tannins, steroids, flavonoids and flavones, phenols, and saponins (Table XI) [90].

Table XI Phytochemical Screening Test Of Sagittaria Trifolia Populations

Phytochemical Constituents	**Treatments (Populations)**				
	MHK	**GL-G**	**JL-O**	**HNW**	**WC-XC**
Alkaloids	-	-	-	-	-
Tannins	+	+	+	+	+
Glycosides	+	+	+	+	+
Terpenoids	-	-	-	-	-
Steroids	+	+	+	+	+
Flavonoids	+	+	+	+	+
Flavones	+	+	+	+	+
Phenols	+	+	+	+	+
Saponins	+	+	+	+	+

As - denotes absence and + denotes presence; Meihekow (MHK); Siping (GL-G); Jilin (JL-O); Harbin (HNW); and Wuchang (WC-XC), reproduced from [90].

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Quantitative Analysis

Morphological & Physiological Parameters

According to Abu-Shahba et al. [91], the authors examined the leaf count, leaf area, leaf length, leaf width and leaf weight to determine the characteristics of lettuce plants in terms of morphology. The authors discovered that in comparison to plants grown in hydroponic systems without bubbles (T1), plants grown in systems with microbubbles (T2), macro bubbles (T3), and sand soil (T4) showed appreciable improvements in morphological traits. Beside the measurement of leaf count, according to Sarkar et al. [92], the authors also used a graduated scale to determine the height of each lettuce plant. All types of growing media notably impact plant height and leaf development [92]. However, the cocopeat-based medium (CP) produced the largest plant height and most leaves [92]. In comparison to plants grown in CP, those cultivated in rice husk-based medium (RH) were shorter and had fewer leaves [92]. In contrast, a modest increase was noted with media composed of equal parts cocopeat, sawdust, and rice husk (EP) (Figure 11) [92].

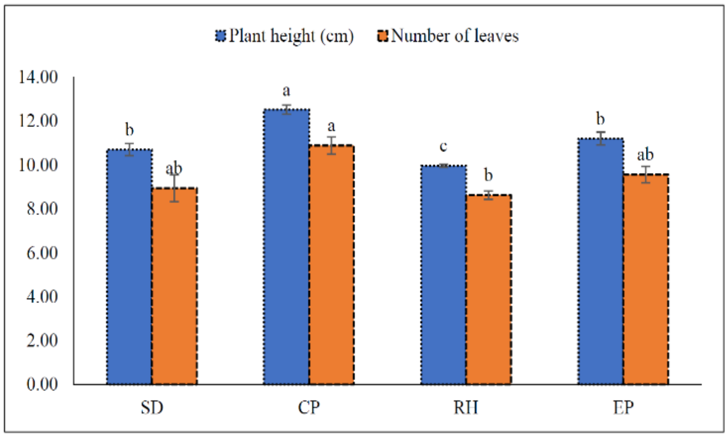

Figure 11: Plant height and leaf number are affected by various growing media, source in **[92]**

The substrate combinations consisting of sawdust, rice husk, and cocopeat in the following ratios are abbreviated as follows: 1:3:1 (SD sawdust); 3:1:1 (CP cocopeat); 1:1:3 (RH rice husk); and 1:1:1 (EP equal proportions of all three organic substrates).

As the physiological growth metrics, Sarkar et al. [92] and Rahman and Inden [93] calculated the sweet pepper plants' root mass ratio (RMR), shoot mass ratio (SMR), leaf area ratio (LAR), and leaf mass ratio (LMR). With regard to different growing media, only the leaf area ratio showed significant variations. On the other hand, the leaf area ratio, leaf area index, leaf mass ratio, shoot mass ratio, and root mass ratio did not vary considerably (Table XII) [92].

Table XII Growth Characteristics Of Lettuce Leaves, Stems, And Roots In Soilless Cultivation

Substrates	**Leaf Area (cm^2)**	**Leaf Area Index**	**Leaf Area Ratio**	**Leaf Mass Ratio**	**Stem Mass Ratio**	**Root Mass Ratio**
SD	117.24 ± 1.74 ^{a}	1.17 ± 0.02 ^{a}	15.12 ± 0.36 ^{a}	0.80 ± 0.01 ^{a}	0.13 ± 0.01 ^{a}	0.07 ± 0.00 ^{a}
CP	119.08 ± 2.10 ^{a}	1.19 ± 0.02 ^{a}	12.65 ± 0.36 ^{b}	0.80 ± 0.01 ^{a}	0.12 ± 0.01 ^{a}	0.08 ± 0.00 ^{a}
RH	115.96 ± 2.31 ^{a}	1.16 ± 0.02 ^{a}	14.48 ± 0.67 ^{a}	0.81 ± 0.01 ^{a}	0.11 ± 0.01 ^{a}	0.07 ± 0.00 ^{a}
EP	117.04 ± 2.18 ^{a}	1.17 ± 0.02 ^{a}	14.60 ± 0.32 ^{a}	0.79 ± 0.00 ^{a}	0.13 ± 0.00 ^{a}	0.08 ± 0.00 ^{a}
F-value	1.56	1.57	5.74	1.97	0.74	1.91
p-value	0.25	0.25	0.01	0.16	0.54	0.17

The table XII is reproduced from [92]. The substrate combinations consisting of sawdust, rice husk, and cocopeat in the following ratios are abbreviated as follows: 1:3:1 (SD sawdust); 3:1:1 (CP cocopeat); 1:1:3 (RH rice husk); and 1:1:1 (EP equal proportions of all three organic substrates).

The leaves, stems and roots of red lettuce plants were individually segregated, and their respective fresh and dry biomass weights were recorded using a precise balance [92]. Immediately following leaf harvesting, the colour of the leaves was assessed using a colour spectrophotometer, which employs the CIE Laboratory lightness (L*), green-red chromaticity (a*), and blue-yellow chromaticity (b*) colour scale [92]. The L* value signifies the lightness parameter, indicating the level of lightness within the sample, with values ranging from 0 representing black (dark) to 100 representing white (light) [92]. The leaves appeared to have significantly darkened, as indicated by the value (L* < 50) [92]. Additionally, every leaf leaned towards positive values of the leaf colour's redness parameter (a*), indicating little to no excessive browning [92]. Furthermore, positive values of the

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yellowness parameter (b*) indicated a tendency for the leaves to be yellow [92]. In different growing media, lettuce leaves showed the highest L values (35.94) for SD, the highest a* values (5.80) for RH, and the highest b* values (13.10) for CP, compared to other media (Figure 12) [92]. All leaves exhibited positive values for the redness parameter (a*), suggesting minimal to no browning [92]. Additionally, all leaves had positive values for the yellowness parameter (b*), indicating a tendency towards yellow (Figure 12) [92].

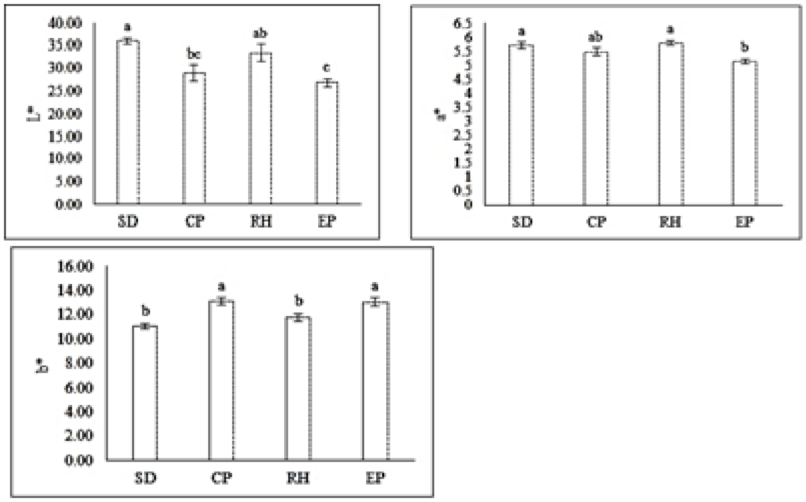

Figure 12: Lightness (L*), green-red chromaticity (a*), and blue-yellow chromaticity (b*) of lettuce leaves under different growing media cultures are presented, source in [92].

The substrate combinations consisting of sawdust, rice husk, and cocopeat in the following ratios are abbreviated as follows: 1:3:1 (SD sawdust); 3:1:1 (CP cocopeat); 1:1:3 (RH rice husk); and 1:1:1 (EP equal proportions of all three organic substrates).

Three developmental stages of the red and green lettuce plants were observed in the physiological responses to lighting treatments: 15 days, 30 days, and 45 days (the last harvest stage) following planting [94]. The physiological parameters of light-saturated instantaneous maximum photosynthetic rate Amax (mol CO^2 m^{-2} s^{-1}) and stomatal conductance (mol H_2O m^{-2} s^{-1}) were measured using the LI-COR 6400 Highly Portable Ambient Photosynthesis System [94]. In comparison to the white spectrum, plants with red spectral bands with a maximum at 660 nm and the blue spectral bands with a maximum at 450 nm with a ratio of 1:1 (R/B450 (1:1)), as well as the blue spectral bands with a maximum at 435 nm with a ratio of 1:1 (R/B435 (1:1)), had a higher photosynthetic rate [94]. According to Alrajhi et al. [94], the photosynthetic rate in green lettuce was significantly higher than that in red lettuce ($p \leq 0.001$) (Figure 13A). Light treatment significantly impacted the stomatal conductance rate ($p \leq 0.001$), with the highest levels observed under the R/B 435 (1:1) light treatment for both green and red lettuce (Figure 13B) [94]. According to Alrajhi et al. [94], the R/B 435 (1:1) light treatment likewise had the highest transpiration rate ($p \leq 0.001$). Figure 13C [94] shows that there was no significant interaction between light treatment and lettuce variety ($p = 0.446$) or the influence of lettuce variety ($p = 0.998$) on transpiration rate.

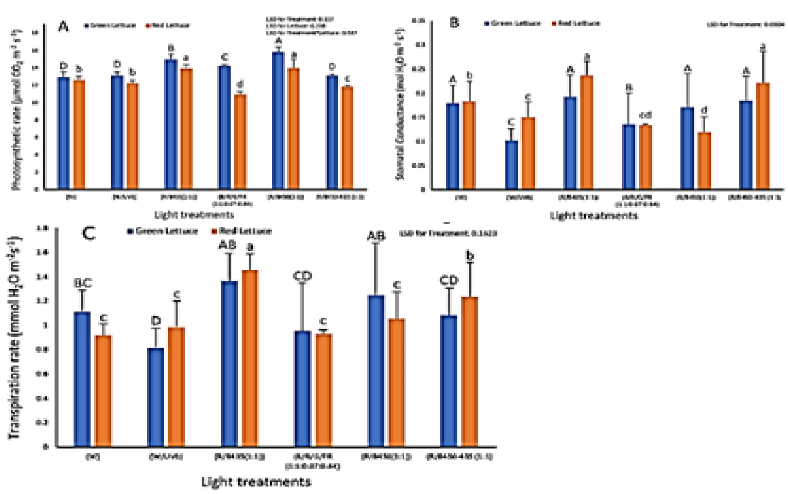

Figure 13: The effect of LED light spectrum on (A) photosynthetic rate (μmol CO2 m−2 s−1), (B) stomatal conductance (mol H2O m−2 s−1), and (C) transpiration rate (mmol H2O m−2 s−1) was studied in green lettuce (Locarno variety) and red lettuce (Carmoli variety), source in [94].

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Biochemical Parameters

Basic Chemical Composition

The basic chemical composition was determined by applying the AOAC method (Association of Official Analytical Chemists) according to Sularz et al. [95]. The amount of ash in lettuce was determined by burning samples in a muffle furnace in accordance with AOAC protocol No. 930.05 [95]. In terms of dry weight (d.w.), the ash content of lettuce varied between 18.35 and 22.00 g/100 g. Nonetheless, Sularz et al. [95] found no statistically significant difference in the ash content between the potassium iodate (KIO_3), 5-iodosalicylic acid (5-ISA), and 3.5-diiodosalicylic acid (3.5-diISA) treatment. Nevertheless, Mobeen et al. [96] determined the moisture and ash content of leafy vegetables using the weight difference approach. According to Mobeen et al. [96], the moisture content varied between 8.02 and 14.77 mg/g fresh weight (f.w.). *Chenopodium album* and *Brassica juncea* were the leafy vegetable species used as samples in the study by Mobeen et al. [96] that were obtained from the market and horticulture garden in the Faisalabad area, Punjab, Pakistan, respectively. According to Mobeen et al. [96], these leafy vegetable species' ash content and moisture content showed a similar pattern, where the *Brassica juncea* had the highest moisture level. In contrast, the *Chenopodium album* had the lowest moisture content.

Sularz et al. [95] measured the total amount of dietary fibre and crude fat content of the lettuce plant by employing a readily accessible test kit under AOAC protocol No. 991.43 and the Soxhlet extraction method (AOAC protocol No. 935.38), respectively. According to Ahmed et al. [90], the carbohydrate content can be calculated using the difference approach, wherein the total moisture, minerals, fat, protein, and fibre values are deducted from the total. Hence, Sularz et al. [95] subtracted the sum of dietary fibre, fat, ash, and protein from 100 in order to estimate the amount of digestible carbohydrates. Sularz et al. [95] discovered a statistically significant decrease in the amount of crude fat in the vegetable when KIO_3 was applied to lettuce instead of 5-ISA and 3.5-diISA but no statistically significant variations in the amount of digestible carbohydrates and dietary fibre were discovered in the lettuce samples for any of the three treatments.

On the other hand, Sularz et al. [95] determined the total protein content using Pearson's micro Kjeldahl method under AOAC protocol No. 950.36, which involved the digestion, distillation, and last titration of the sample to determine the nitrogen value, which is a substance's precursor for protein [97]. Asaolu et al. [98] and Mobeen et al. [96] multiplied the obtained nitrogen value by a factor of 6.25 to calculate the leafy vegetables' protein content. Sularz et al. [95] discovered that the protein content of lettuce statistically significantly rose due to the application of KIO_3 compared to the treatments with 5-ISA and 3.5-diISA. Mobeen et al. [96] established the protein content limits of *Lactuca sativa*, a leafy vegetable species in both horticulture gardens and market samples by applying the same method. In contrast, Lowry et al. [99] conducted a method presented by Wu [100] to determine plasma proteins in which the colour reaction that Folin's phenol reagent produces was observed for the determination. Abu-Shahba et al. [91] utilised the same method to measure the total soluble protein of lettuce by determining the colour intensity of proteins in solution or readily soluble in dilute alkali at 750 nm using a spectrophotometer after the addition of diluted Folin reagent. The standard bovine serum albumin curve was then used to calculate the total soluble protein level [91]. When comparing the leaves of lettuce plants cultivated in hydroponic systems with microbubbles (T2), macro bubbles (T3), and soil (T4) to those grown in hydroponics without bubbles (T1), the total soluble protein content rose considerably.

Chlorophyll and Carotenoid

Plant lipids classified as isoprenoid pigments include carotenoids, chlorophylls, sterols, prenylquinones, and prenols [101]. These pigments are involved in photosynthetic processes [101]. Light absorption is measured on aqueous acetone extracts containing 80% chlorophyll to determine the chlorophyll content [102]. A wavelength spectrophotometer (649, 665, and 470 nm) was used to calculate the optical density, which allowed for the determination of the content of carotenoid and chlorophyll (a, b) [91, 103]. Equations for the quantitative determination of chlorophylls, pheophytins, and carotenoids rely on their spectral properties and absorption coefficients as fundamental factors [101]. Abu-Shahba et al. [91] employ the subsequent formulas for computing the chlorophyll levels in lettuce leaves:

$$Chlorophyll\ a(mgg^{-1}) = 11.63(A_{665}) - 2.39(A_{649}) \quad (1)$$

$$Chlorophyll\ b(mgg^{-1}) = 20.11(A_{649}) - 5.18(A_{665}) \quad (2)$$

$$Total\ (a+b)(mgg^{-1}) = 6.45(A_{665}) + 17.72(A_{649}) \quad (3)$$

On the other hand, the determination of carotenoid content was done based on the following equation that was introduced by Lichtenthaler [101] according to Abu-Shahba et al. [91]:

$$Carotenoid(mgg^{-1}) = 1000 * OD470 - 1.82 Chlorophyll\ a - 85.02 Chlorophyll\ b/198 \quad (4)$$

Abu-Shahba et al. [91] found that plants cultivated in hydroponic systems with microbubbles (T2), macro bubbles (T3), and soil (T4) had a considerably increased level of Chl a, Chl b, and Chl a + b in their lettuce leaves when compared to those produced in hydroponics without bubbles (T1). However, there was no discernible difference in the carotenoid content between plants grown in T1 and T3, and plants grown with microbubbles (T2) had a much higher carotenoid content than all other treatments [91]. According to Abu-Shahba et al. [91], plants cultivated with microbubbles (T2) had the highest amounts of chlorophyll a, chlorophyll b, chlorophyll a + b, and carotenoids. Plants grown with macro bubbles (T3) and soil (T4) had the lowest values.

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Vitamin C

Alrajhi et al. [94] utilised High-Performance Liquid Chromatography (HPLC) analysis to determine the green and red lettuce plant's ascorbic acid (vitamin C) content. The plant extract underwent filtration using a 0.45 µm filter paper, and the resulting liquid was examined using HPLC. According to Alrajhi et al. [94], a NewcrcmBH column (3.2 × 50 mm, 3 µm) with a mobile phase consisting of 50% acetonitrile (MeCN) and 50% water (H_2O) was used in this HPLC analysis [94]. Moreover, this analysis utilised 0.5% phosphoric acid (H_3PO_4) as a buffer and UV detection was performed at 275 nm with a flow rate set at 0.5 mL/min [94]. Alrajhi et al. [94] found that vitamin C levels were affected significantly by the light lettuce variety ($p = 0.018$), treatment ($p \leq 0.001$), and their interaction ($p \leq 0.001$). The highest vitamin C content was found in green lettuce plants under light treatment combining red spectral bands with a maximum at 660 nm and blue spectral bands with a maximum at 450 nm with a ratio of 1:1, supplemented by far-red and green light in a ratio of 1:1:0.07:0.64 (B/R/G/FR (1:1:0.07:0.64)) [94]. In contrast, the highest vitamin C levels in red lettuce plants were observed under the white light and R/B 450 (1:1) light treatment [94]. Furthermore, green lettuce plants showed the lowest vitamin C levels under the R/B 450 (1:1) light treatment [94]. On the other hand, the vitamin C levels in red lettuce plants were negatively impacted by the light treatment consisting of white light (50% cool white and 50% warm light) and ultraviolet B (UV-B) radiation with an intensity of 0.3 microwatts/cm² (W/UV-B), as measured using a UV light meter [94]. This treatment was applied for one hour per day over 24 hours each day for a week before harvest [94].

Sarkar et al. [92] utilised the indophenol method that had been described by Nielsen [104] to determine the vitamin C content in lettuce. This method involved titration where each sample was titrated with the indophenol dye solution until a light rose pink hue persisted for five seconds [92]. The amount of dye used in the titration was determined to calculate the vitamin C content using a standard curve constructed using ascorbic acid concentrations between 10 and 100 mg/L [92]. Sarkar et al. [92] discovered the highest levels of vitamin C content in lettuce plants cultivated with CP compared to SD, RH and EP.

III. Macro- and Micromineral

The Dumas method, which was developed in 1831, predominantly employed a dry oxidation approach, whereas the Kjeldahl method, which was developed in 1883, primarily used a wet oxidation procedure, are the two widely accepted methods used to quantify total nitrogen [105]. Many of the Kjeldahl techniques used for total nitrogen analysis of soils and other substances were regarded as macro techniques prior to about 1960, and they required the use of Kjeldahl digestion flasks with volumes ranging from 350 to 800 ml [105]. In contrast to the 1960s, semi-micro versions of these techniques—which use smaller flasks, between 30 and 50 ml—became more popular and are currently used more frequently than macro techniques [105]. Due to their lower equipment costs, fewer reagent and soil sample requirements, improved safety, and decreased need for large amounts of laboratory space, semi-micro approaches have supplanted macro methods in the field [105].

Abu-Shahba et al. [91] also employed this semi-micro Kjeldahl method to determine the nitrogen content of lettuce plants and they found that the nitrogen content of lettuce plants grown in hydroponic systems with microbubbles was significantly higher than that grown in systems without bubbles. According to Figure 16a-d, the results revealed that the lettuce plants cultivated in a hydroponic system with microbubbles (T2), macro bubbles (T3), and soil (T4) had significantly higher levels of nitrogen (N), phosphorus (P), potassium (K), and magnesium (Mg) in lettuce leaves compared to those produced in hydroponics without bubbles (T1). Nonetheless, there was no noticeable difference in the P content in the lettuce leaves between plants grown in T1 and T4 whereas there was no evident variation in the N and Mg content of plants grown in T3 and T4 [91]. On the flip side, the lettuce plants cultivated in T2, T3, and T4 had lower Calcium (Ca) content in lettuce leaves than those grown in T1 according to Figure 14e [91].

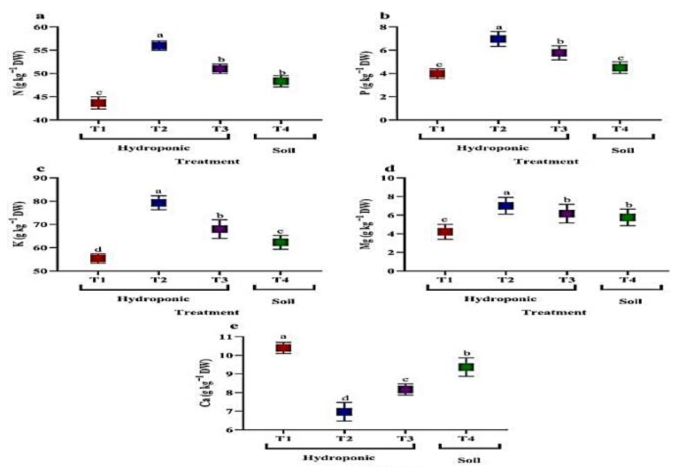

Figure 14: The variation found in the levels of mineral content in lettuce leaves of plants cultivated in hydroponics without bubbles (T1), hydroponics with microbubbles (T2), hydroponics with macro bubbles (T3), and soil (T4) after 30 days of cultivation, source in [91].

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The inductively coupled plasma-optical emission spectrometry (ICP-OES) technique was employed by Kalisz et al. [106] to determine the concentrations of silver (Ag), aluminium (Al), barium (Ba), cobalt (Co), lithium (Li), tin (Sn), strontium (Sr), titanium (Ti), antimony (Sb), and all other rare-earth elements in cauliflowers. By considering the average weight of the curds, their dry weight content, and the element concentration in the dry weight, which indicates the plant's capacity to accumulate elements, they were able to calculate the average concentration of all trace elements in cauliflower curds. Sularz et al. [95], like Kalisz et al. [106], measured the concentrations of phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), sulphur (S), sodium (Na), boron (B), copper (Cu), iron (Fe), manganese (Mn), zinc (Zn), molybdenum (Mo), strontium (Sr), lithium (Li), barium (Ba), aluminium (Al), vanadium (V), and cadmium (Cd) in lettuce plants. Sularz et al. [95] discovered that the application of different forms of iodine caused the dramatically increase in the levels of certain macro-minerals, including Mg, Na, and Ca, as well as the trace elements (B, Fe, Mo, Ba, Al, V, Cd) in the lettuce plants. According to Sularz et al. [95], the control plants had the greatest copper concentration whereas the biofortified lettuce with 5-ISA had the highest iodine concentration. However, the levels of N, P, K, and S content in the treated and control plants did not alter significantly [95].

Total Phenol Content

Christofi et al. [107] and Abu-Shahba et al. [91] utilised the Folin-Ciocalteau method to determine the total phenol content of lettuce leaves and microgreens, respectively. This method involves the combination of lettuce extract, sodium carbonate (Na_2CO_3), and Folin-Ciocalteau reagent to create a blue-coloured complex known as molybdenum blue since the phenols react redoxally with phosphomolybdic acid in the alkaline Folin-Ciocalteau reagent [91]. A UV-visible spectrophotometer was used with absorbance values at 650 nm to compare with those from gallic acid standards for measuring the concentration of phenols [91]. Abu-Shahba et al. [91] revealed that lettuce leaves cultivated in hydroponic systems with microbubbles (T2), macro bubbles (T3), and soil (T4) had significantly higher phenol content than plants grown in hydroponic systems without bubbles (T1) in which the plants cultivated in T2 had the greatest phenol content.

IV. Conclusion

A review on the smart indoor system with implementation of IoT was presented. We do brief explaining the notes on site description such as light source and we have categorize the electronic components into different categories such as sensing unit, controller unit, data storage unit and wireless communication protocols. The characteristics of the equipment are been listed in this review paper, the user can select the suitable devices to make or revise own smart system. The user should consider the scale of the indoor farming when choosing the appropriate components because there are other factors such as the power consumption, power efficiency and crop yield production will affect the whole system performance. Challenges and limitations have been introduced in this review paper and may take into consideration so we can gain insights and aim to improve it in the future. There are some case studies mentioned in this review paper that can use for the reference when employing a smart indoor system and knowing the necessary methodologies to proceed with the indoor farming. Last but not least, the lettuce's growth is examined in different sections and parameters, the result is been discussed in this review paper and compared with the other researches to enable more valuable insights to be obtained.

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