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MEASUREMENT AND MONITORING OF RESPIRATION OF TOMATO AND BANANA USING INTERNET OF THINGS (IoT) AND ELECTRONIC SENSORS

Tanmay H. Bhatt[1]*, V.B. Bhalodiya[1] and Vishal I. Mehra[2]

[1]Department of Food Process Engineering, College of FPT&BE, Anand Agricultural University, Anand, Gujarat, India.
[2]Department of Agricultural Sciences, College of AIT, Anand Agricultural University, Anand, Gujarat, India.
*Corresponding author E-mail : bhatt.tanmayh@aau.in

ABSTRACT

Fruit respiration is one of the important metabolic processes in which fruits, convert their stored carbohydrates into energy. This process is essential for the fruit's growth, development and ripening. Respiration in fruits involves the intake of oxygen (O_2) and the release of carbon dioxide (CO_2) and water vapor (H_2O) as by-products. When fruits are exposed to higher temperatures, their respiration rates generally increase, leading to faster ripening. Conversely, lower temperatures can slow down respiration, extending shelf life. However, keeping them fresh during transportation is hard, due to this it causes disease and spoilage, which leads to a lot of wastage of fruits. Therefore, a monitoring system for fruits is required to track and manage various aspects such as quality, ripeness, and storage conditions throughout the supply chain. The study proposes to develop an IoT-based monitoring system, which is important for ensuring optimal quality and checking the shelf life of Tomato and Banana as they have high nutritional value and health benefits. With advances in modern technologies and advantages over traditional methods of measuring respiration parameters, the same can be measured by using electronic sensors. The system is comprised of Arduino UNO Wi-Fi board, in which a program is made in an Integrated Development Environment. DHT 22 sensor is used for measuring Temperature & Humidity. Oxygen, Carbon Dioxide and Ethylene gas sensors are used for measuring gas concentrations in a closed storage chamber (made of acrylic) of 2'x 2' x 2' and further can monitored over days and time. In this study, all the collected real-time data from the sensors will be viewed on the Graphic User Interface of the computer, mobile, and server systems.

Key words : Arduino Uno Wi-Fi Rev.2 Module, Tomato, Banana, IoT, Electronic Sensors.

Introduction

Fruit respiration is the process, where fruits convert sugars into energy, releasing carbon dioxide and water. This metabolic activity is influenced by various factors including humidity, temperature, and gas exposure. Higher temperatures can accelerate respiration rates, leading to faster ripening and spoilage. Conversely, lower temperatures can slow down respiration, extending shelf life. Proper management of these factors is essential for maintaining fruit quality during storage and transport.

It is a process by which cells generate energy they consume. It is a major factor which affect the self-life and ripening process of bananas and tomatoes. In respiration rate major factors which affect the ripening is gases, temperature and relative humidity. Therefore, monitoring of the Temperature, Relative Humidity, Ethylene, Oxygen and Carbon Dioxide is necessary.

Understanding the complex processes of fruit respiration and optimal storage conditions is key to ensuring quality and prolonging shelf life. This presentation will explore the critical factors that influence these crucial post-harvest considerations. Fruit respiration is a critical physiological process that significantly impacts energy. This biochemical process is essential for maintaining cellular functions and supporting metabolic activities within the fruit. Post-harvest quality, shelf life, and overall market value of fruits. It is a fundamental physiological process in fruits, where they consume oxygen and release carbon dioxide. This process generates energy for the fruit's growth and development. Understanding fruit respiration is crucial for effectively storing and preserving fruits to maintain their quality and extend their shelf life.

Respiration in fruits is a biochemical process where organic molecules, primarily carbohydrates like glucose, are broken down to release energy

Chemical Equation

$$C_6H_{12}O_6+6O_2\rightarrow 6CO_2+6H_2O+Energy \quad (1)$$

Storage parameters

Proper storage parameters are crucial to maintaining the quality, freshness and nutritional value of fruits after harvest. By optimizing these parameters, the respiration rate can be managed, spoilage reduced and shelf life extended. Key storage parameters include humidity temperature, atmospheric composition, and the management of ethylene exposure.

Related works

The traditional approach of measuring respiration in a closed container with the help of a gas analyser for Royal Delicious Apple (Mangaraj and Goswami, 2008). Gas Chromatography with a closed system method was used to measure the respiration of Litchi fruit. Regression analysis and enzyme kinetics were the two methods used to replicate the respiration rate of the Litchi fruit. The data was gathered using a closed system at different temperatures ranging from 0 to 30°C. According to the enzyme kinetics model, uncompetitive inhibition is how O_2 and CO_2 concentrations affect respiration. This model's parameters were fitted to the Arrhenius equation to determine pre-exponential factors and activation energy. To forecast respiration rates, regression coefficients were also used. This showed how temperature had a substantial influence on the model parameters for efficient modified environment packaging design (Mangaraj and Goswami, 2011).

To predict respiration rates based on O_2 and CO_2 concentrations as well as storage temperature, a respiration rate model for guava was created utilizing enzyme kinetics and the Arrhenius equation. The model showed that temperature has a major impact on the parameters and that respiration is influenced by O_2 and CO_2 through uncompetitive inhibition. Activation energy and pre-exponential factors for temperatures between 0°C and 30°C were determined by fitting the Arrhenius equation to the parameters of enzyme kinetics. Strong agreement between the validated data and the experimental results was seen at 12°C, with mean relative variances of 8.95% for O_2 consumption and 8.02% for CO_2 evolution (Mangaraj and Goswami, 2011).

Now, different sensors were used for measuring the relative humidity temperature and gas composition in a close acrylic box of 1 cubic foot and IoT was used to monitor the real time data from anywhere. Different electronic sensors were also used to measure the gas respiration. In this paper, an Internet of Things (IoT) based system that measures temperature, mixed gas concentrations and relative humidity of tomatoes kept in an acrylic chamber measuring one cubic foot in size under ambient conditions is researched. The system was developed using inexpensive sensors. Real-time data in this system can be viewed on cloud servers and home computers as well (Bhatt and Mehra, 2023).

Hence, monitoring of the above-discussed methods is important. Various traditional methods were used in measuring respiration. With advance in modern electronic semiconductor technology. it is possible to measure the same with the help of electronic sensors and further can monitored through IOT based Systems.

Materials and Methods

Respiration sensors are vital tools in the agricultural and food storage industries, designed to monitor the respiration rates of fruits during storage and transportation. These sensors help in assessing the metabolic activity of fruits by measuring the levels of gases such as oxygen (O_2), carbon dioxide (CO_2) and ethylene (C_2H_4), which are directly involved in the respiration process. By providing real-time data on these gases, respiration sensors enable better control of storage environments, thereby enhancing fruit quality and extending shelf life.

Methodology

Hardware and Software Design

The Arduino Uno Wi-Fi is the new Arduino Uno with the Wi-Fi module. The board is based on the ATmega328 with ESP8266 Wi-Fi Module integrated. The Wi-Fi Module is a self-contained System on Chip with integrated TCP/IP protocol stack that can provide access to a Wi-Fi network, or act as an access point. It supports OTA (over-the-air) programming, either for the transfer of Arduino sketches or Wi-Fi firmware. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 Analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable, with an AC-to-DC adapter to get started.

The program is made in Arduino Integrated

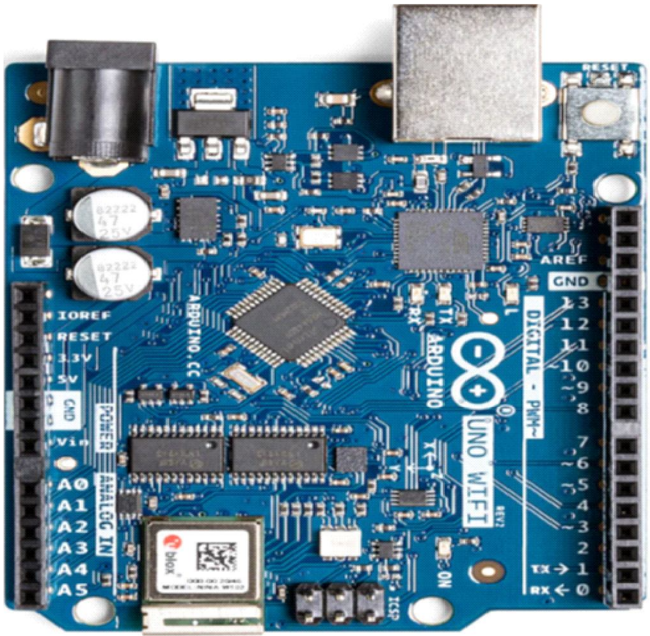


Fig. 1 : Arduino UNO Wi-Fi board (Rev.2) ABX00021 (2024).

Fig. 2 : DHT22 Temperature & Humidity Sensor DHT22 (n.d.).

Fig. 3 : Ethylene Gas Sensor.

Electrochemical Ethylene Gas Sensor ME3-C_2H_4 (2023)

Fig. 4 : Oxygen Gas Sensor.

ME2-O2-Ω20 (2023)

Fig. 5 : Carbon Dioxide gas sensor.

MH-Z19C CO_2 Module (2023)

Development Environment (IDE), which is a cross-platform application written in functions from C and C++. It is used to write and upload programs to Arduino-compatible boards. It has two parts: Editor and Compiler. The former is used for writing the required code, while the latter is used for compiling and uploading the code into the given Arduino Module.

The complete system, comprising of Arduino UNO Wi-Fi Board and sensors for measuring temperature and humidity using DHT 22, Oxygen Gas Sensors, Carbon Dioxide Sensors, and Ethylene Gas Sensors, has been used to measure different types of gas concentrations.

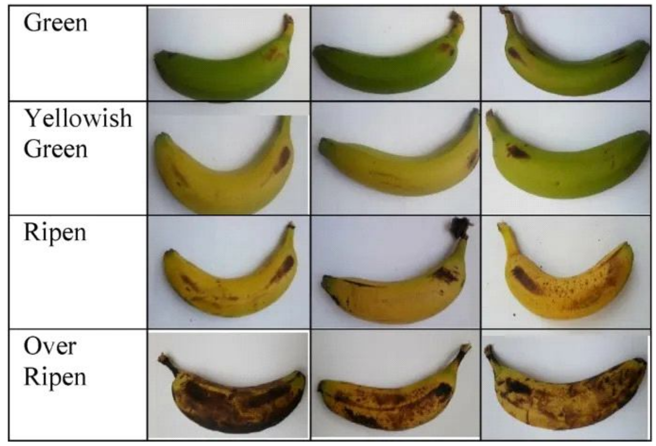


Fig. 6 : Ripening Stages and Color variation in Banana (Saranya *et al*., 2022).

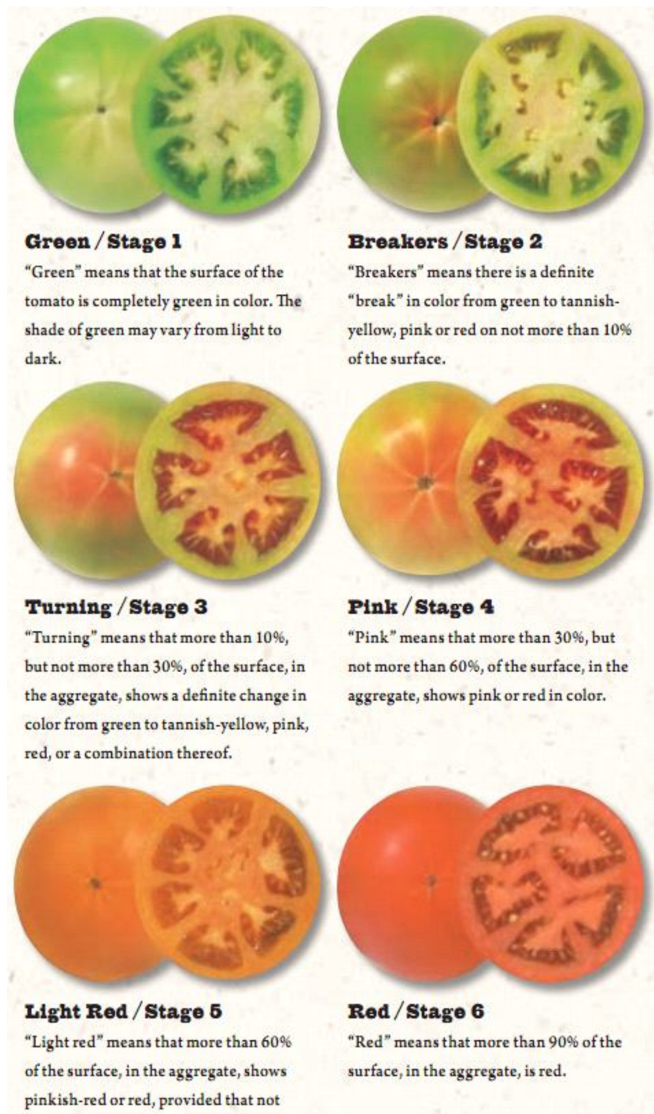


Fig. 7 : Colour variation in Tomato & Tomato grades (Garcia *et al*., 2019).

Selection of fruits

In this experiment Unripen Tomato which is Green (as shown in Fig. 6) in color is used because it is available

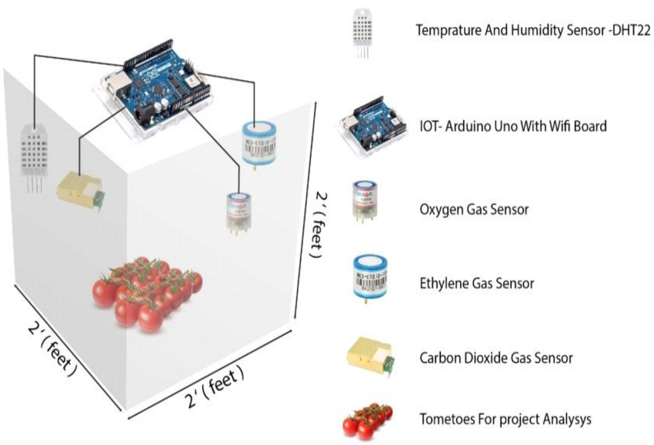


Fig. 8 : Conceptual design of storage chamber.

Table 1 : Specifications of Arduino UNO Wi-Fi board (Rev.2).

Arduino Microcontroller	
Microcontroller	AT Mega 4809
Architecture	AVR
Operating Voltage	5V
Flash Memory	48 KB
SRAM	6 KB
EEPROM	256 byte
DC Current per I/O Pins	40 mA (I/O Pins)
General	
Input Voltage	7-12 V
Digital I/O Pins	20
Interfaces	I2C, SPI, UART
PWM Output	5
Analog I/O Pins	6 Input/output pins
Weight	8.9 g
Product Code	ABX00021

UNO WiFi Rev2 (2024)

throughout the year and it has very high processing value. It is used in preparing many dishes like soups, sauces, and salads, and It is rich in vitamins A and C. However, keeping them fresh during transport is hard, especially at room temperature, where they can get diseases. Storing tomatoes improperly can have a range of negative effects on their quality and shelf life, which causes Texture Changes, Flavor Loss, Ripening Issues which can lead to a lot of waste and they can lose moisture and become more prone to germs, making them less appealing to buyers.

Similarly, Bananas are used in making chips, flour, powder, puree, juices, fruit bars etc. Its peel is also very useful in making fibres. Factors like temperature, humidity, and exposure to ethylene gas affect how bananas ripen. Bananas spoil quickly and need careful handling throughout their journey from farm to store. Proper care

Table 2 : Specifications of Oxygen gas sensor.

Model	ME2-O_2-Ω20
Detection gas	O_2
Measurement Range	0 ~ 25% Vol
Max detecting concentration	30%Vol
Sensitivity	(0.08-0.25) mA (In air)
Response timeÿT90	≤ 15S
Load resistance (recommended)	100Ω
Repeatability	<2% output value
Stabilityÿÿmonth	<2%
Zero driftÿ-20!^ÿ40!	≤1%vol
Storage temperature	-20^{0}C~50^{0}C
Storage Humidity	0%~99%RH (no condensation)
Pressure range	normal atmosphere±10%
Anticipated using life	2 years
Detection gas	O_2

ME2-O2-Ω20 Oxygen Sensor (2023)

Table 3 : Specifications of Ethylene gas sensor.

Model	ME3-C_2H_4
Detection gas	C_2H_4, ethylene sensor
Detection range	0-100ppm
Max. range	200 ppm
Sensitivity	0.04±0.012 uA/ppm
Filter	Filtering SOX/NOX and H_2S
Resolution	0.5ppm
Tem. range	-20°C-50°C
Pressure range	standard atmosphere ±10%
Response time(T90)	<30S
Humidity range	15%—90%RH
Bias voltage	no
Reproducibility	1% of signal output
Output	Linearity output
Anticipated using life	3 years in air

Electrochemical Ethylene Gas Sensor ME3-C_2H_4 (2003)

during picking, packing, and shipping is crucial to avoid bruising. Keeping the right storage conditions can help bananas last longer and reduce waste. Regular quality checks at each step ensure that both tomatoes and bananas reach consumers in good condition (Mohapatra *et al.*, 2010).

Conceptual Design of the Storage Chamber

An airtight test storage chamber, which is made by acrylic material, with capacity of 50 Kgs (approx.) of

Table 4 : Specifications of Carbon Dioxide gas sensor.

Model No.	MH-Z19C
Detection gas	CO_2
Working Voltage	5.0±0.1V DC
Average Current	<40mA (@5V power supply)
Peak Current	125mA (@5V power supply)
Interface Level	3.3V (Compatible with 5V)
Detection range	400~10000ppm (optional)
Output Signal	Serial Port (UART) (TTL level 3.3V)
	PWM
Preheat Time	1 min
Response Time	T90 <120s
Working Temperature	-10 ~ 50^0C
Working Humidity	0 ~95% RH (No condensation)
Storage Temperature	-20~60^0C
Weight	5g
Life Span	>10 years

MH-Z19C NDIR CO_2 Module (2023)

Table 5 : Specifications of Temperature and Humidity Sensor.

Model	DHT22
Power supply	3.3-6V DC
Output signal	digital signal via single-bus
Sensing element	Polymer capacitor
Operating range	Humidity 0-100%RH; temperature -40~80 Celsius
Accuracy	humidity +-2%RH(Max +-5%RH); temperature <+-0.5 Celsius
Resolution or sensitivity	humidity 0.1%RH; temperature 0.1Celsius
Repeatability	humidity +-1%RH; temperature +-0.2Celsius
Humidity hysteresis	+-0.3% RH
Long-term Stability	+-0.5% RH/year
Sensing period	Average: 2s
Interchangeability	Fully interchangeable
Dimensions	Small size 14*18*5.5mm; big size 22*28*5mm

DHT22 (n.d.)

fruit (Tomato, Banana) (one fruit at a time) to be kept inside it, with 20% headspace volume and whose Dimensions (l × w × h) are Length: 60 cm, Width: 60cm Height: 60 cm (2'x 2' x 2') was fabricated. The Arduino UNO Wi-Fi Board is then connected on this storage chamber.

Four DHT-22 sensors and One Ethylene gas sensor, Two O_2 gas sensor, Two CO_2 gas sensor are connected to Arduino Uno Board Wi-Fi Board. All the sensors were kept hanging inside the chamber. This all hardware is fixed on the top plane surface of the storage chamber, from where it is used to collect the data from connected sensors. The entire setup so developed is shown in Fig. 8.

Design of the proposed system

When connections are done, the developed hardware is also connected to the PC to Arduino Integrated Development Environment Version 2.3.3 (software) in order to upload the developed sketch for assessing the system & for the detection of various gases and to measure the humidity and temperature. After successfully uploading the sketch, the test is carried out by putting different fruits one after another (Tomato & Banana) into the storage chamber properly. Fruits are kept safely inside the chamber and the system is attached. As time goes, the released gas concentration from the respective fruit measures the temperature and humidity with the help of sensors. This data is then transferred to the Cloud server which can be analyzed on computer.

Observations to be recorded

Measurement of respiratory and storage parameters such as temperature, humidity, gas concentrations (Oxygen, Carbon Dioxide and Ethylene) is to be taken. Following observations are to be taken

- Temperature vs. days of ripening
- Temperature vs. time of stored fruits
- Relative Humidity vs. days of ripening
- Relative Humidity vs. time
- Oxygen Gas Concentration vs. days of ripening
- Oxygen Gas Concentration vs. time of stored fruits
- Ethylene Gas Concentration vs. days of ripening
- Ethylene Gas Concentration vs. time of stored fruits
- Carbon Dioxide Gas Concentration vs. days of ripening
- Carbon Dioxide Gas Concentration vs. time of stored fruits

The Internet of Things

IoT Architecture for Respiration Measurement and Monitoring

IoT Devices : Sensors (CO_2, O_2, temperature, humidity) are be placed in or near the banana storage areas These sensors continuously monitor the environment and the respiration rate of bananas.

Connectivity : Sensors are connected to a central hub or gateway, through a Wi-Fi Module which is built inside the Arduino Module itself.

Data Collection and Cloud storage : The data from the sensors are transmitted to a cloud platform where it can be stored, processed, and analyzed.

Data analysis : The data collected (CO_2, O_2 levels, temperature and humidity) is processed and analyzed.

Alerts and Visualization : A dashboard or mobile app can be used to provide real-time insights into the respiration rate, temperature, and humidity levels. Alerts can be sent to users (farmers, distributors, or logistics companies) if conditions go outside the optimal range (*e.g.*, excessive CO_2 or high temperature), indicating potential spoilage or ripening issues.

Cloud Server and Storage : Cloud computing is a model for delivering computing resources over the internet. This model enables users to access a shared pool of computing resources on demand. These resources include servers, storage, networking, applications, and services. Cloud computing offers scalability, flexibility, and cost-effectiveness by allowing users to only pay for what they use, without having to manage or maintain physical hardware. It refers to storing data on remote servers maintained by a cloud service provider (CSP). Users can upload, access, and manage their data via the internet, without needing to maintain physical storage infrastructure on-site. It is part of the broader cloud computing ecosystem, and it enables the storage, management and retrieval of data in a highly scalable and secure environment.

How Cloud Storage Works

Cloud storage is managed and maintained by a third-party cloud service provider. These providers operate large data centres that house numerous **virtual servers**. As demand for storage increases, new virtual servers are provisioned dynamically to handle the load. Users interact with these systems via an internet connection, either through a web portal, mobile app, or **API** (Application Programming Interface). Cloud Storage Workflow is as follows:

Data Upload

Data is transferred to the cloud through an internet connection. This can happen through a web interface, a mobile app, or an integrated system within an organization's IT infrastructure.

Data Storage

Once uploaded, the cloud provider stores the data across multiple virtual machines or physical servers in one or more data centres. The provider uses advanced algorithms and architectures (*e.g.*, object storage) to ensure that data is efficiently stored and can be retrieved with low latency.

Data Redundancy

To ensure data durability and availability, cloud storage providers typically implement **redundancy mechanisms**. Data is replicated across different machines, data centres, and regions, which ensures that even if one server fails, the data can still be accessed from another server.

Data Access

Users can access their data at any time through a secure internet connection. Access is granted through a **web portal**, a **mobile application**, or directly through an **API** for automated data retrieval and storage.

Cloud Storage Models

- **Public Cloud**: The cloud infrastructure is owned and operated by a third-party provider, and resources are shared among multiple customers (tenants). Examples: Amazon Web Services (AWS), Google Cloud, Microsoft Azure.
- **Private Cloud**: The cloud infrastructure is used exclusively by a single organization, either hosted on-premises or by a third-party provider. It offers more control and security but comes with higher costs.

Benefits of Cloud Storage

- **Reduced Capital Expenses**: Traditional storage solutions require significant upfront investment in physical hardware, which needs to be managed and maintained. Cloud storage eliminates these costs, allowing users to shift to a pay-as-you-go model.
- **Scalable Pricing**: Cloud storage pricing is typically based on the amount of storage used. As data volume grows, users can scale up capacity without the need to invest in new physical infrastructure.

Integration of IoT and Cloud

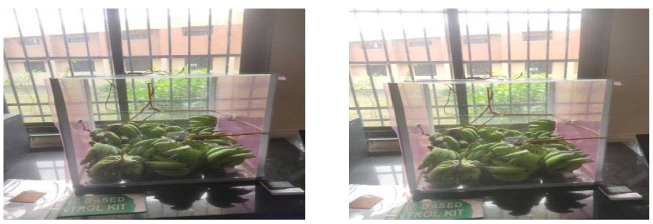
By combining IoT with Cloud computing, the data from sensors can be processed and analyzed in real-time. This can drive automated decision-making and provide real-time data to help optimize the ripening process, ensuring bananas reach their peak quality before reaching consumers. This combination has the potential to revolutionize the agro-industrial sector by making it more efficient, data-driven and responsive to market needs. IoT enables real-time monitoring and control across large-scale operations, while cloud computing provides the infrastructure to store, process and analyze the vast amounts of data generated. Together, they enhance productivity, sustainability, and transparency, creating more informed, connected and adaptable rural communities and supply chains. This synergy not only benefits farmers, managers, and business owners but also empowers consumers with greater insights into the food they consume, ultimately contributing to smarter, more sustainable agricultural practices.

Results and Discussion

Monitoring of Respiration of Banana

Environmental Setup

- An acrylic chamber was used to store bananas under sunlight, likely with the aim of observing the effects of controlled temperature and humidity on the ripening and spoilage processes.

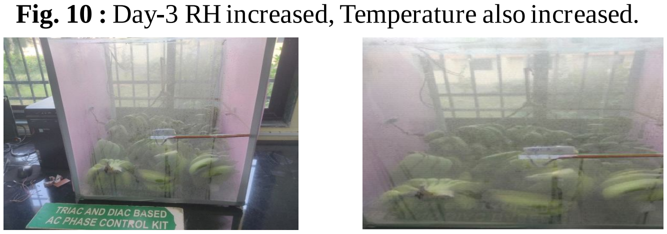


9(a) 9(b)

Fig. 9 : Day-1 RH- Normal Temp. room temperature.

10 (a) 10 (b)

Fig. 10 : Day-3 RH increased, Temperature also increased.



11 (a) 11 (b)

Fig. 11 : Day-4.

12 (a) 12 (b)

Fig. 12 : Day-5.

13 (a) 13 (b)

Fig. 13 : Day-6 Fungus started to grow.

14 (a) 14 (b)

Fig. 14 : Day-7.

- As the bananas respired and transpired, moisture was released, causing the Relative Humidity inside the chamber to reach 99%. This high humidity would accelerate the ripening process by providing moisture to the bananas.

Initial Color Change (Day 3)

- On the third day, condensation of water droplets was observed inside the chamber, indicating high humidity levels. At this point, the bananas began to change colour from green to yellowish-green, signalling the onset of ripening. This is a typical sign that bananas are moving from the immature (green) to the ripe (yellow) stage.

Further Ripening and Gas Formation (Day 5)

- By the fifth day, the bananas continued to ripen, showing further colour changes. This process is accompanied by the production of gases, such as CO_2, which are released naturally during the ripening of bananas.
- As bananas ripen, their rate of respiration increases, leading to more CO_2 production. This is part of the reason why the fruit releases a noticeable amount of CO_2 as it ripens. The ripening process itself is also associated with a variety of chemical changes that affect the flavor, texture, and aroma of the banana.

Microbial Growth and Spoilage (Days 7-9)

- As the moisture released into the chamber created a humid environment, this likely promoted the growth of microorganisms, including fungi, on the bananas. This was evident by the appearance of fungal growth on the bananas by the seventh day.
- By the ninth day, the bananas had become fully ripe and were heavily infected with fungal and microbial growth. This microbial activity would accelerate the

Fig. 15 : Day-9.

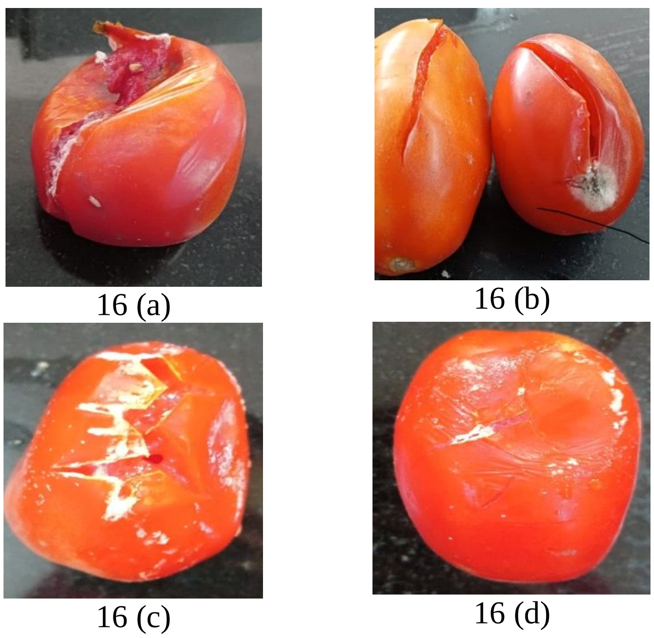


Fig. 16 : Shrinkage in Tomato.

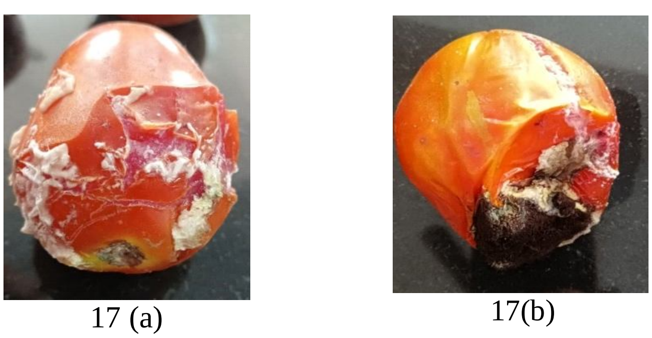


Fig. 17 : Microbial Spoilage in tomato.

spoilage of the fruit.

- In addition to microbial growth, there were also noticeable changes in the texture and physicochemical properties of the bananas, including softening and potentially off-flavors associated with spoilage.

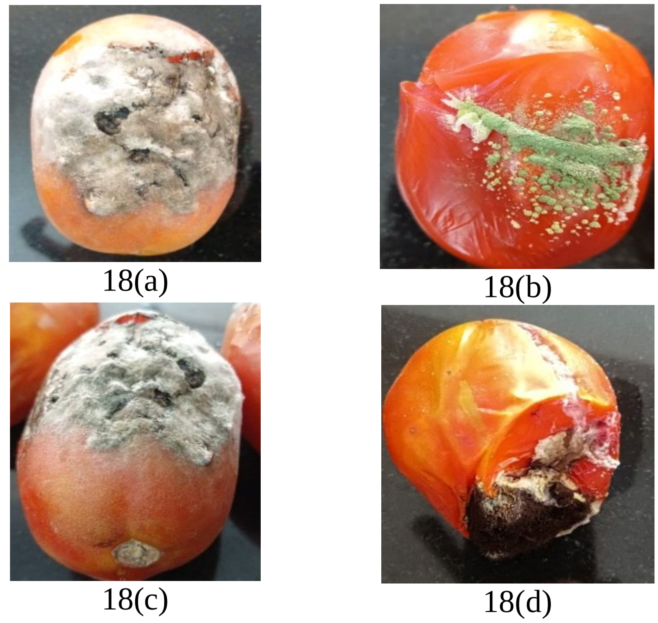


Fig. 18 : Yeast and Mold growth in tomato.

Monitoring of Respiration of Tomato

As a Result, after a week, the appearance of tomato, spoilage and Microbial growth Shrinkage of outer layer occurred due to different parameters including respiration, ripening, due to the sealed container, etc.

Discussion

Respiration and Transpiration

Bananas and tomato both releases moisture through respiration (metabolic processes) and transpiration (water loss through the skin). These processes are important for maintaining internal humidity and accelerating ripening in confined spaces like the acrylic chamber.

High Humidity

The high relative humidity (99%) maintained in the chamber contributed to a more rapid ripening process. However, it also created a favourable environment for fungal and microbial growth, leading to spoilage.

Fungal and Microbial growth

The increase in moisture and temperature, coupled with the natural sugars in the bananas, likely promoted the growth of microorganisms. Fungal growth is common in moist, warm conditions and this was evident after several days. The fungal growth likely contributed to further degradation of texture, causing soft spots and potential spoilage

Color and Texture changes

The bananas transitioned from green to yellowish-green as they ripened and then eventually became fully ripe with significant textural changes. Ripened bananas typically soften, and their starches convert to sugars, leading to changes in flavour. Shrinkage has been observed in tomatoes which is primarily caused by moisture loss, temperature fluctuations, and improper storage conditions.

The study demonstrated that high humidity, combined with sunlight exposure, accelerated the ripening of bananas but also contributed to spoilage through microbial growth. This highlights the balance between moisture needed for ripening and the potential for over-ripening and fungal infections under uncontrolled conditions. To extend the shelf life of selected fruits, it's essential to manage humidity levels, temperature, and microbial exposure effectively.

Conclusion

Respiration measurement using an IoT-based monitoring system is developed for real-time monitoring of data of storage conditions of selected fruits, remotely using mobile applications. Studies can be done for large-scale systems like Commercial Greenhouse with the help of Wireless Sensor Networks (WSNs) and other environmental parameters can also be monitored. The performance evaluation of the developed system can be done using a storage chamber of different materials and different dimensions. Different types of hardware like NVIDIA Jetson Boards can be used for efficient and faster computation and Programmable Logic Controller networking, provides a variety of communication and control options for PLCs, computers and other devices. Further, Studies can be done to find out the respiratory behavior and storage conditions of Underutilized Fruits by selecting the appropriate Hardware and Software platforms. By integrating IoT technologies to measure the respiration rate of bananas, it is possible to optimize storage conditions, reduce spoilage, and improve the quality control process in the supply chain. This can ultimately lead to more sustainable agricultural practices, lower waste, and better consumer experiences. The combination of real-time monitoring, data analytics and automation makes IoT a powerful tool for managing the ripening and shelf-life of bananas.

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