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Temperature and pH Monitoring System Design in the Fermentation of Cocoa Beans Based on Android

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Abstract

Fermentation of cocoa beans was a key step in increasing their quality. Temperature and pH have an impact on the fermentation process' performance. Temperature and pH measurements in the cocoa bean fermentation process have been done using thermometer and pH meter, and have been heavily impacted by experience and knowledge. The goal of this research was to create a temperature and pH monitoring system for the fermentation of cocoa beans using an android platform. The sensor is able to measure temperature and pH during the fermentation process, and the sensor reading data is displayed on the android display, according to the system design criteria. A temperature sensor, pH sensor, microcontroller, TP-Link or WiFi modem, ThingSpeak (data storage), and smartphone make up the system's hardware. Arduino CC software version 1.8.14 was used to create the software. The system hardware was made up of numerous components, including the NodeMCU ESP32 microcontroller, SKU SEN0161 pH sensor, DS18B20 temperature sensor, 4.2k resistor, jumper cable, and 5-volt charger adaptor. The electronic system circuit was packed in a plastic box with 14.5 cm length, 9.5 cm width, and 5 cm height, with a weight of 250 g. The use of DS18B20 as temperature sensor showed an accuracy of 99.9%. Results of this study showed that during the fermentation process, the pH varies with a coefficient of variation of 23.4% and tended to increase. Based on the performance test findings, the monitoring system can read temperature and pH for 112 hours or 6 days. The reading for the temperature of cocoa beans ranged from 27.2°C to 41.8°C, with the pH fluctuating between 2.50 and 7.10.

Keywords: monitoring system, fermentation, cocoa beans, temperature, pH

INTRODUCTION

Cocoa bean fermentation was a curing process of previous drying of cocoa beans in which the pulp was reduced as well as color and flavor were developed (De Vuyst & Weckx, 2016). Monitoring the composition, structure, functionalities, and metabolic potential encoded at the level of DNA of fermented cocoa pulp-bean mass metagenome was of great importance for food safety and quality implications (Gutierrez *et al*., 2021). The study of Aculey *et al*. (2010) demonstrates the potential of colorimetry and spectroscopic methods as valuable tools for determining the fermentation degree of cocoa beans.

Another issue with Indonesian cocoa beans was the poor quality of the beans, which was primarily due to poor post-harvest processing, particularly fermentation (Tarigan & Iflah, 2017; Ariningsih *et al.,* 2021). Considering that most cocoa beans moved from farmers to traders have not been fermented, the buyer's price was lower than the market one (Manalu, 2018). Fermentation of cocoa bean's has been shown to enhance beans' quality and farmer's income (Djauhari *et al.*, 2013). Fermentation creates characteristics of chocolate flavor, transform the color of the cocoa bean chips from purple to brown and hollow, and eliminate the bitter and astringent taste to produce high-quality cocoa beans (Permentan, 2012). A controlled fermenting process can increase the quality of cocoa beans (Apriyanto *et al*., 2020). During the fermentation process, some chemical components like fat content, pH value, chocolate flavor, and volatile chemicals that produce scent will grow (Tarigan & Iflah, 2017), because microbes destroy carbohydrates in the pulp, alcohol and organic acids are produced, which are then distributed into the beans (Apriyanto *et al*., 2017). The anaerobic phase and the aerobic phase are the two stages of fermentation. The temperature and pH values throughout the fermentation process will determine the success of the fermentation process. Increased temperature and pH suggest an increase in microbial activity involved in cocoa fermentation, namely the activity of anaerobically converting sugar to ethanol, followed by the creation of lactic acid and acetic acid (Mulyawanti *et al*., 2018).

Until now, temperature and pH measurements in the cocoa bean fermentation process have been done manually with a thermometer and pH meter. Manual temperature and pH readings necessitate knowledge, accuracy, and measurement time that must be repeated regularly. Observing the fermentation of cocoa beans helps to identify the problem. Observations show that monitoring temperature and pH directly with a thermometer and pH meter causes various complications during the fermentation process. Furthermore, measurements were not taken frequently or were not taken at all. To maintain the quality of fermented cocoa beans, information on temperature and pH during fermentation was required.

Based on the current issues, a temperature and pH monitoring system that can give temperature and pH information in real-time was required in the cocoa bean fermentation process. The sensor must be able to measure temperature and pH during the fermentation process, and the sensor reading data must be displayed on the android display, according to the system design criteria. The goal of this research was to create a temperature and pH monitoring system for the fermentation of cocoa beans using an android platform.

MATERIALS AND METHODS

Site Description

Experiments to design and build a temperature and pH monitoring system was carried out from May to December 2021 at the Electronics and Instrumentation Laboratory of the Department of Agricultural Engineering and Biosystems, Padjadjaran University, Bandung. A series of equipment monitors that have been finished were then tested at Indonesian Industrial and Beverage Crops Research Institute (Balittri) in Sukabumi, West Java.

The materials employed in this study were divided into two categories: materials for electronic circuit monitoring system manufacturing and materials for system testing. An adapter, breadboard 400 points, jumper cable, WiFi Modem, NodeMCU ESP32 microcontroller, 4.7k resistor, SKU pH sensor

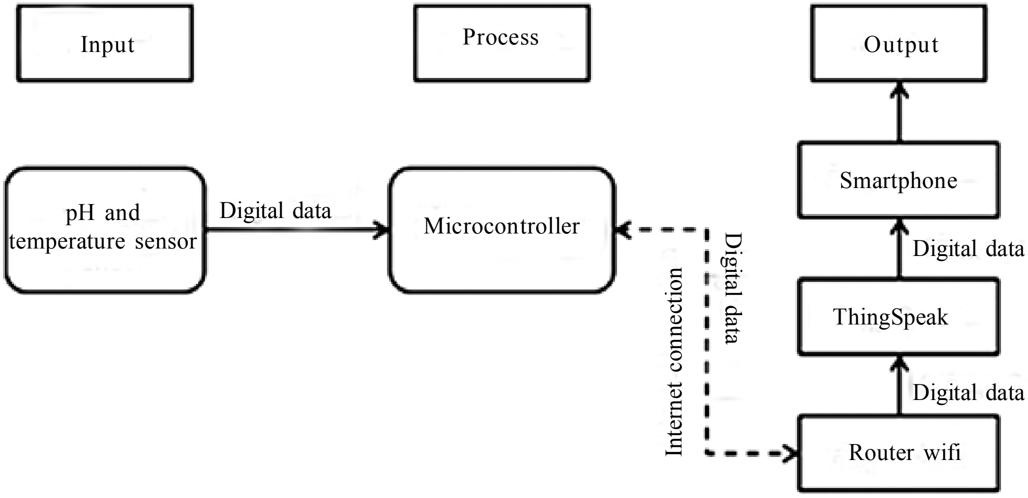

Figure 1. System block diagram

SEN0161, DS18B20 temperature sensor, and smartphone were used to make the electronic circuit of the monitoring system (Android). The monitoring system was tested with ready-to-ferment bulk cocoa beans from the Pakuwon Experimental Garden, as well as a buffer solution that served as a calibration for the pH sensor.

The appropriate hardware and software are identified based on Figure 1 so that the system can function properly. The chosen hardware was then put together into a single unit, and the device was set up so that the data read by the sensor can be presented on the android display.

Hardware Development

A temperature sensor, pH sensor, microcontroller, TP-Link or WiFi modem, ThingSpeak (data storage), and smartphone make up the system's hardware. The following types of hardware functionalities used in the system were chosen based on the system's needs and advantages. The pH sensor SKU SEN0161 also serves as a temperature detector. A pH detector was built within the DS18B20 temperature sensor. The key component that governs the temperature and pH components was the NodeMCU ESP32 microcontroller. The advantages of the ESP32 include that it has more pinouts than other microcontrollers, a larger memory, Bluetooth 4.0 low energy features, and Wifi, making the Internet of Things easy to implement (Muliadi *et al.*, 2020). TP-Link or Wifi Modem serves as a link between the NodeMCU ESP32 and the internet, allowing data to be sent to the server. ThingSpeak was a data storage system that allows smartphones and pH and temperature meters to communicate over the internet. Smartphone as a versatile device with Android OS may monitor through loaded applications. Then, each component was put together into a single unit in such a way that the system can function properly. Figure 2 shows a schematic of the monitoring system's hardware structural architecture.

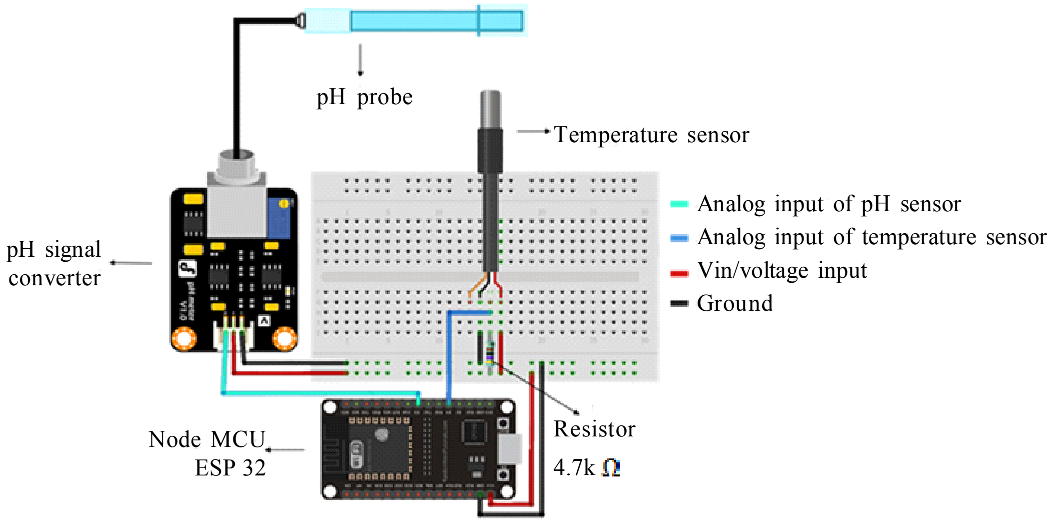

Figure 2. Hardware schematic

Software Development

The microcontroller was programmed using a personal computer/laptop that was connected to the internet during the software design stage. Microcontroller programming need programming software, one of which was Arduino IDE, which supports the C programming language. The algorithm was written in the Arduino IDE software and then uploaded to the NodeMCU ESP32, which was already connected to a computer via USB (Figure 3). After the program was appropriate and can detect the value of pH and temperature, the next stage was to develop the interface, which will be presented on the smartphone screen so that it was easy to monitor and can be seen anywhere and at any time.

The Arduino software version 1.8.14, which was one of the software that supports the C language, was used for programming. The C programming language was well-known and trusted for creating microcontroller programs. Not only was the Arduino software used in the Arduino family, but there was also a library for the NodeMCU microcontroller that can be installed easily in each version. The benefit of using a NodeMCU microcontroller was that it comes with both a WiFi and Bluetooth module.

Each component's programming was done independently first, and then the coding was put together in one program after each component has been tested and calibrated to ensure that it was working properly. The pH and temperature monitoring system were comprised of three different programs: the ESP32 WiFi connectivity program and the ThingSpeak server, the SKU SEN0161 pH sensor program, and the DS18B20 temperature sensor program.

After the tool has been thoroughly tested, the next stage was to put it into practice by putting it to the test during cocoa fermentation. The test was conducted at the cocoa plantation division of Balittri. The

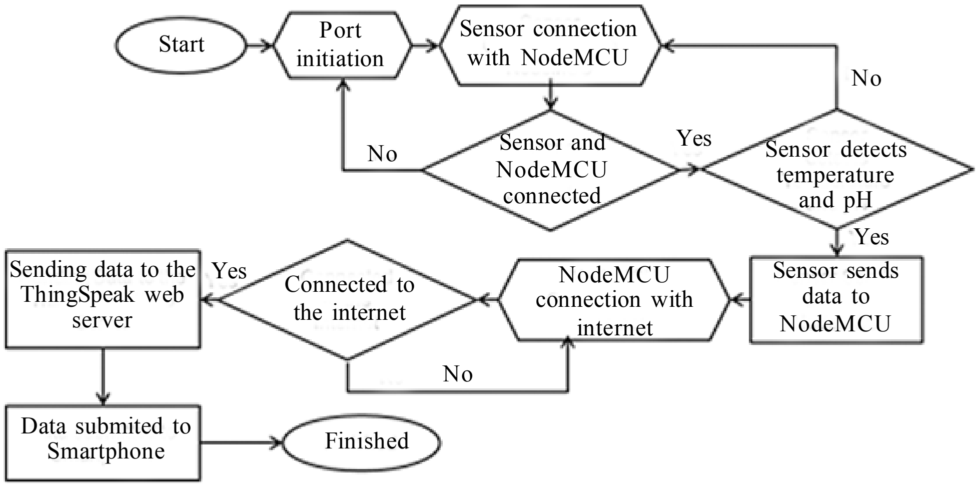

Figure 3. Flowchart of software development

percentage of system correctness from each test scenario was used to evaluate the system. The purpose of calculating the percentage of accuracy is to find out where the user and what are the optimal conditions for using this instrument.

System Test

Functional and performance tests are part of the system testing process. Functional testing ensures that every component of the system performs as expected. The following are some of the functional tests that were performed.

NodeMCU ESP32 Microcontroller Testing

Running a simple application on this microcontroller tries to establish a WiFi connection between the ESP32 NodeMCU and a router or the internet. Checking the port used on the analog pin of the NodeMCU ESP32 with the program that has been created to see if the data sent by the pH sensor was correct.

pH Sensor Testing

The purpose of pH sensor testing is to determine the properties of the pH sensor as well as the voltage created by the electrode when a pH value was applied to it in a variety of pH buffer solutions. The sensor's output was analog data, which will be transformed to a voltage value, then which will be converted to a pH value using the Arduino IDE software. The obtained readings were then compared to the optimal pH probe criterion.

Temperature Sensor Testing

The purpose of the temperature sensor testing is to demonstrate that the sensor used in the study was capable to perform accurate measurements and determining the error value and accuracy of sensor measurement data. The test was conducted by submerging the temperature sensor probe in water and comparing the findings to the thermometer's readings. It can be seen that the temperature from the thermometer count was linear with temperature from the sensor (Figure 4)

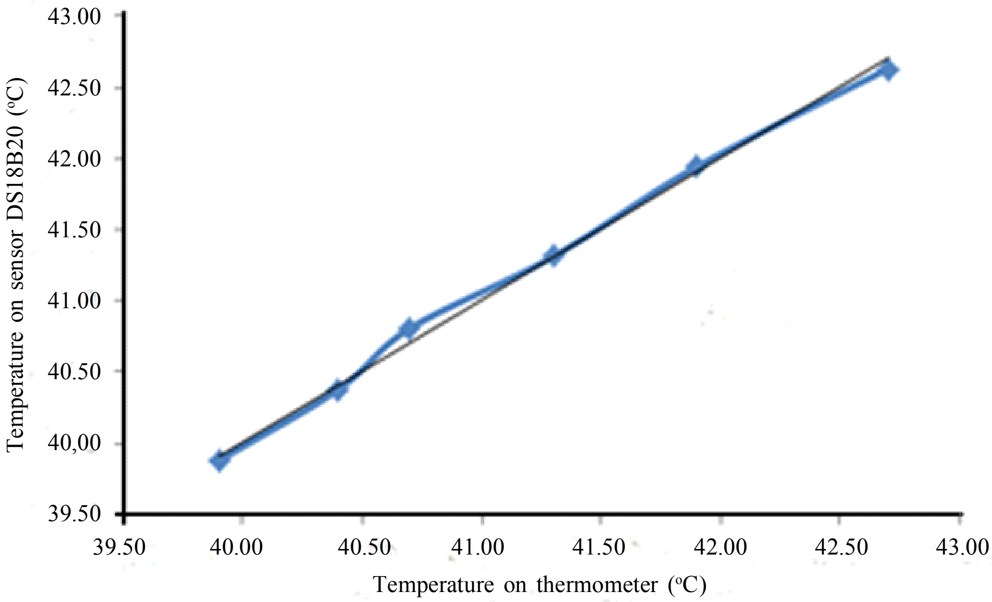

Figure 4. Relationship between temperature on sensor and on thermometer

The next stage was to evaluate the temperature and pH monitoring system's performance after ensuring that all of the components were working properly. The entire system performance in the process of monitoring pH and temperature during the fermentation process was the goal of the performance test. The position of the two detectors was put at one time during the fermentation process of 26 kg of cocoa beans that were stored by stacking method in a box measuring 35 cm x 35 cm x 35 cm that would be covered with a burlap bag. In general, the use of a 35 cm x 35 cm x 35 cm fermentation box aims to accommodate farmers whose harvests of cocoa pods are small so that they can ferment to produce dry cocoa beans that still meet the Indonesian National Standard (SNI) standard for cocoa beans 2323:2008. With the same intention, Arinata *et al* (2020) conducted a study with several smaller fermentation box sizes. Optimal fermentation results were achieved at a size of 23.5 cm x 23.5 cm x 29.5 cm, at a temperature of 45.2°C, for 60 hours with a moisture content of 78% w/w (included in the SNI standard for cocoa beans). The temperature and pH of wet cocoa bean pulp for 24 hours in a pile of cocoa beans were measured every one hour for 6 days of fermentation. Based on the research of Arinata *et al.* (2020) and Hayati *et al.* (2012), they found that fermentation for 6 days was the best and produced aroma, color, and texture which consumers liked. Every two minutes, the program that has been uploaded to the microcontroller sends data from the sensor readings. Observations will be presented on the smartphone screen in the form of a graph, with the ability to set and display the reading time as desired. The research findings will be temporarily saved as data on the ThingSpeak server, where they can be downloaded in a variety of forms, including JSON, XML, and CSV (formats from Microsoft Excel). Data from every two minutes of readings on each sensor will be saved in a database, where processing will be done in preparation for data retrieval every one hour. The data was processed using VBA in Microsoft Excel, which retrieves data every one hour from sensor readings.

RESULTS AND DISCUSSION

Temperature and pH Monitoring System

The temperature and pH monitoring system was made up of several electronic (hardware) and software. The NodeMCU ESP32 microcontroller, SKU SEN0161 pH sensor, and DS18B20 temperature sensor, as well as additional supporting components such breadboards, 4.2k resistors, and jumper cables, make up the electronic system circuit. Figure 5 shows the electronic system circuit in greater detail.

The voltage supply of the equipment used did not need a great quantity of power; a cable and a charger adapter with a voltage of 5.0 V was enough. The electronic system circuit was 14.5 cm length, 9.5 cm width, and 5 cm tall, with a weight of 250 g. To eliminate outside influence, the electronic system circuit was encased into a 3 mm thick plastic box.

The software was created with the Arduino CC software version 1.8.14, which was one of the C-language-supporting programs. The pH and temperature monitoring system were divided into three programs: the ESP32 WiFi networking program and the ThingSpeak server, the SKU SEN0161 pH sensor program, and the DS18B20 temperature sensor program. A minimum smartphone with Android version 4.1 and an application that can display readings as required. Figure 6 depicts the main interface of the interface. There were numerous channels and fields on each channel that can hold up to eight fields of any data type.

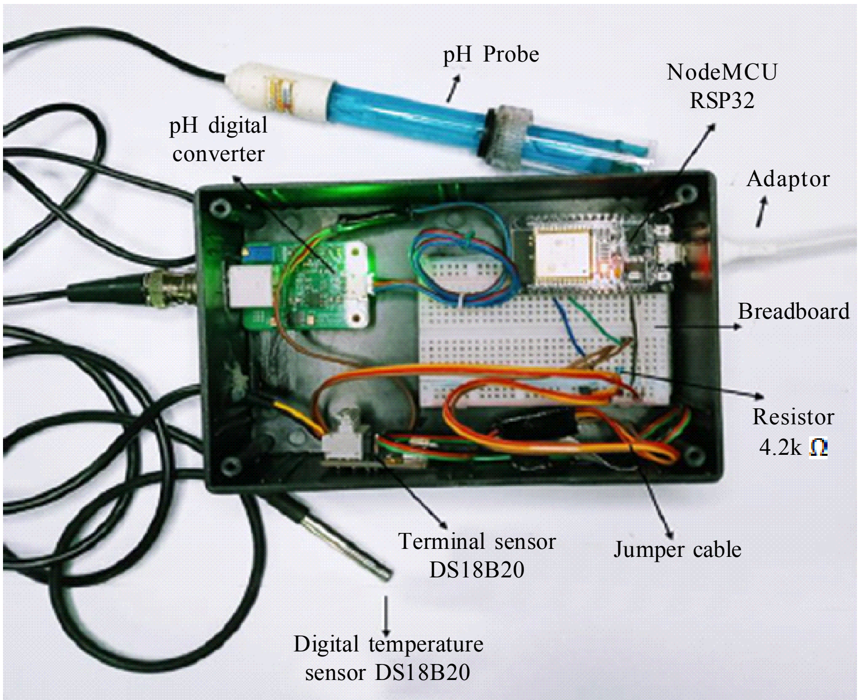

Figure 5. Prototype of temperature and pH monitoring system

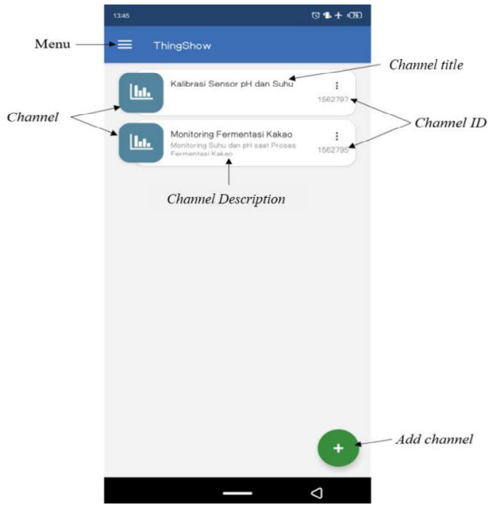

Figure 6. A first look at the application

The monitoring system was an important aspect of the electronic system and software functions comprehensively. The monitoring system's operation begins with the reading of temperature and pH data during the fermentation of cocoa beans. For 24 hours, data measurement was taken every 2 minutes. The temperature and pH sensor readings will be automatically sent to the ThingSpeak database server for temporary storage by the ESP32 nodeMCU that was already connected to the internet. After that, the data was processed and shown on the smartphone interface. As long as the smartphone was linked to the internet, observations can be made from anywhere. Figure 7 illustrates the operating concept of the monitoring system.

Temperature and pH Monitoring Calibration

Before the system was used to monitor the fermentation of cocoa beans, temperature and pH sensors must be calibrated. DFRobot's SKU SEN0161 pH sensor has one advantage: it can autonomously calibrate itself by altering the measured buffer solution. The monitor serial column was used to write the available text input during the calibration procedure. Calibration starts with the input "enterph," which enters the calibration mode phase, then the probe was dipped into the buffer solution, followed by the word "calph," which automatically detects and calibrates the buffer solution used. The final step was to exit calibration mode by writing "exitph," and a successful calibration writing will appear on the serial monitor. Figure 8 shows the calibration results using a pH 6.86 buffer solution.

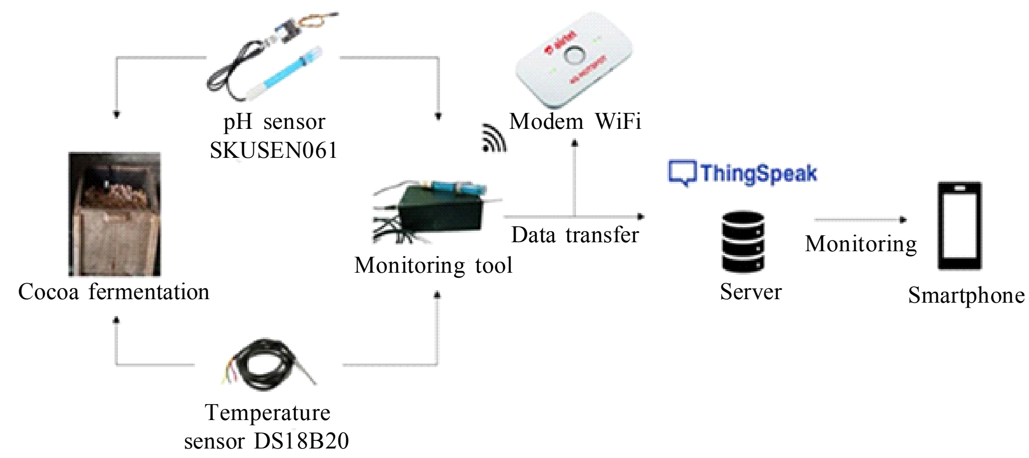

Figure 7. Temperature and pH monitoring system performance during the cocoa bean fermentation process

Manual temperature sensor calibration was performed by comparing the DS18B20 temperature sensor reading to a mercury thermometer reading as a reference. In addition, the DS18B20 temperature sensor reading error was estimated (Sulaeman & Kusnadi, 2011).

Table 1. Temperature sensor calibration results (°C)

Test	Temperature Sensor DS18B20	Mercury thermometer	Error (%)
1	42.63	42.70	0.16
2	41.94	41.90	0.10
2	41.31	41.30	0.02
3	40.81	40.70	0.27
4	40.38	40.40	0.05
5	39.88	39.90	0.05
	Error Average		0.11

Table 1 shows that the DS18B20 temperature sensor has a high accuracy value (99.89%) and was close to typical sensor readings in general.

Performance of the Temperature and pH Monitoring System

The temperature and pH sensor probes were inserted into the cocoa beans in the fermentation box to conduct the test. For six days, the fermentation process was carried out in the wooden box. Arinata *et al.* (2020) found that fermenting cocoa beans for six days in a wooden box resulted in the most excellent fermented cocoa beans. According to Hayati *et al.* (2012), six days of cocoa bean fermentation generated the scent, color, and texture was that the panelists preferred.

Temperature and pH sensors can read the temperature and pH of cocoa beans throughout the fermentation process and display data on the android display, according to functional tests. A WiFi modem was used as a sent pH during the fermentation process.

During the fermentation process, data collected by the sensor will be displayed as a graph that will increase every 2 minutes, as well as the most recent sensor reading data in the box. A Microsoft office file containing the data displayed on the system can be downloaded. Excel can be used to further process the data. Figure 8 shows that the temperature of cocoa beans started at 27.19°C and increased with increasing fermentation time.

The temperature of the cocoa beans reached 41.75°C after 6 days of fermentation or 112 hours. The temperature increased at a rate of 0.38°C per hour during the fermentation process. According to Mulato *et al.* (2005), the temperature fluctuates between 25 and 45°C at the start of the fermentation and rises to 45 to 55°C as the fermentation progresses. The increase in temperature in the fermentation process was caused by increased microbial activity, according to Hartuti *et al.* (2018). Curing time and air temperature were two factors that influence fermentation temperature. In this experiment, the fermentation process was a little uneven, which was indicated by the temperature not reaching 45-50°C. This might be since the fermented wooden box was not fully filled because during the experiment the Balittri lacked cocoa beans. Another possibility is due to the weather in Balittri when the experiment was carried out, there was continuous rain causing the environmental temperature to drop.

Besides temperature, pH is an important element in the fermentation process. Figure 8 shows that the pH varies with a coefficient of variation of 23.38% and tends to increase. The lowest pH reached 2.50, while the highest reached 7.10, for an average pH of 4.90. Microbial activity was linked to pH fluctuations throughout the fermentation process. The increase in pH during the fermentation process was caused by the loss of citric acid caused by yeast degradation, whereas the decrease in pH was caused by the diffusion of lactic acid and acetic acid into the bean interior (Sari *et al.*, 2021). Acid production from pulp degradation was critical for fermentation, with acid diffusion into the beans

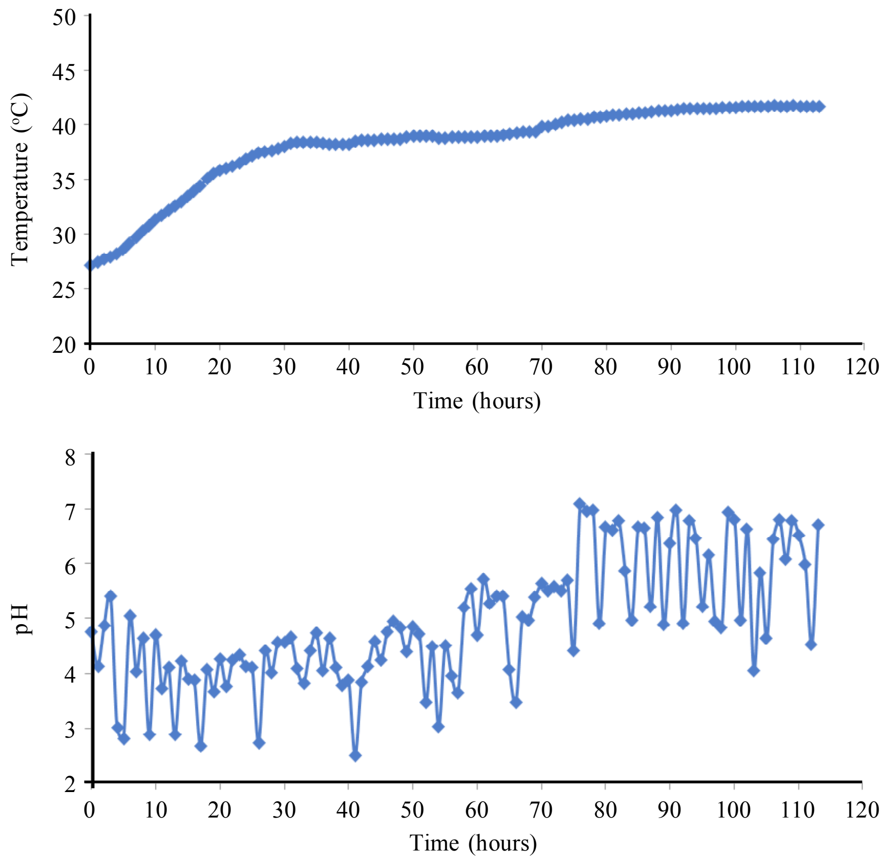

Figure 8. Temperature and pH during the fermentation of cocoa beans

signaling the start of a biochemical reaction in the beans that will result in well-fermented cocoa beans (Apriyanto *et al*., 2017).

CONCLUSIONS

With components consisting of NodeMCU ESP32, DS18B20 temperature sensor, and SKU SEN0161 pH sensor, combined with communication media between smartphones and sensor detection devices via internet, a temperature and pH monitoring system has been successfully created in the cocoa bean fermentation process. Based on the results of the performance test, the monitoring system succeeded in reading the temperature and pH during the fermentation process which lasted for 112 hours or 6 days. The temperature of the cocoa beans ranged from 27.19°C to 41.75°C, with the pH fluctuating between 2.50 and 7.10.

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