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ON-OFF CONTROL SYSTEM FOR TEMPERATURE AND HUMIDITY IN A SWEET POTATO CHIP DRYER USING HEATING ELEMENTS

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ABSTRACT

Sweet potato chips are an innovative processed product that has been widely developed by Micro, Small, and Medium Enterprises in several regions. Most sweet potato chips are dried using traditional methods, such as direct sun drying. However, during the rainy season, solar heat cannot be used optimally, so the drying process tends to be slower. This study aims to create a temperature and humidity control system for a sweet potato chip drying machine using a dual air heater. Based on previous studies, temperature and humidity are crucial factors in food drying because they affect product quality. Earlier studies on drying ovens and temperature-controlled drying systems have shown that on-off control can maintain temperatures close to the setpoint with a simple design and low cost for small-scale applications. In addition, the development of microcontrollers such as the Arduino Uno has made it possible to design automatic control systems that can monitor and adjust temperature and humidity in real time. The method used in this study was the design of a laboratory-scale drying oven equipped with a DHT22 sensor, an Arduino Uno, and an on-off control system using a heater and fan as actuators. System performance was evaluated under several operating conditions, namely with and without the control system. The results showed that the control system was able to maintain the dryer temperature within the range of 45°C to 55°C and relative humidity between 35% and 40%. In addition, increasing the drying time from 2 hours to 3 hours reduced the product moisture content from 39.9% to 7.7%.

Keywords*: chip, dryer, heating, humidity, temperature.*

I. INTRODUCTION

SWEET potato chips are an innovative processed sweet potato product widely developed by Micro, Small, and Medium Enterprises (UMKM) in several regions. Sweet potato chips are popular among many Indonesians, which has led to the emergence of new and increasingly popular flavor variations [1]. Sweet potato chips are processed through several stages, including drying.

The problem with drying sweet potato chips is that they are typically dried using traditional methods, in which the chips are directly exposed to sunlight. Although this method is relatively simple and inexpensive, the drying process is very time-consuming. Sweet potato chips must be left under the hot sun for hours, or even days, depending on humidity levels and the intensity of the sunlight. Furthermore, reliance on sunny weather makes this method inefficient, especially in areas with long rainy seasons.

During the rainy season, the use of sunlight to dry sweet potato chips is severely limited because persistent rain prevents optimal drying. Even on cloudy days, solar heat cannot be fully utilized [2] because clouds block much of the sunlight that would otherwise speed up the drying process. As a result, the drying process becomes slower and less efficient, which increases the risk of damage or a decline in the quality of the final product.

The drying process is a crucial step in the production of sweet potato chips because it reduces the water content to a certain level to ensure a crispy texture and a longer shelf life. Poorly controlled drying can lead to lead to product quality degradation, such as darker color, a texture that is too hard or too soft, and a reduction in the natural flavor of the sweet potato [3], [4]. The main contributing factors are unstable fluctuations in temperature and humidity during the drying process. A drying temperature that is too high can degrade important compounds such as carbohydrates and vitamins, while a temperature that is too low inhibits water evaporation and results in longer drying times [5]. Similarly, high humidity in the drying room can slow the evaporation rate and cause the product to dry unevenly [6], [7].

Research related to sweet potato drying has been conducted in several previous studies. Putra et al. [8] showed that drying sweet potatoes in a cabinet dryer at temperature variations of 50–60°C significantly affected the water content and bioactive compounds such as β-carotene and anthocyanin. Adra et al. [9] found that the drying method significantly affected the antioxidant stability of purple sweet potatoes (Ipomoea batatas Var. Ayamurasaki), where drying at high temperatures could substantially reduce anthocyanin levels and antioxidant activity. Meanwhile, Sabahannur [10] reported that drying temperature and blanching treatment had a significant effect on the physical and chemical quality of sweet potato flour, especially on the water content and color of the final product. In addition, Novison et al. [11], in research on the sweet potato drying process, showed that increasing the heating temperature can accelerate the drying rate but may reduce energy efficiency if it is not properly controlled.

Based on these studies, it can be concluded that temperature and humidity control are crucial factors in maintaining drying quality [12], [13]. However, most studies still use manual control systems that cannot adjust dynamically to environmental conditions during the process. Several studies have implemented simple switching-based controllers to regulate temperature in drying systems, where relay or on–off controllers are commonly used because of their simple control logic and ease of implementation. Previous research on oven dryers and temperature-controlled drying systems reported that on–off control can maintain the drying temperature close to the setpoint while keeping the system design simple and cost-effective for small-scale applications [14]. In addition, developments in microcontroller technology such as the Arduino Uno allow the design of automatic control systems capable of monitoring and adjusting temperature and humidity in real time [15], [16].

Therefore, this study aims to design and implement a temperature and humidity control system for an Arduino Uno-based sweet potato chip drying machine, using an air heating element as the heat source and a DHT22 sensor to detect temperature and humidity conditions in the drying chamber [17], [18]. The measurement data are displayed directly on the LCD screen when conditions change [19].

This study makes a significant contribution to the development of sweet potato chip drying technology by implementing an Arduino Uno-based automatic temperature and humidity control system. The main contribution of this study is the implementation of a control system that can monitor and regulate temperature and humidity in real time inside the drying chamber. This system uses a closed-loop control mechanism, where temperature and humidity sensors continuously measure environmental conditions and transmit data to the controller. The controller compares the measured values with a predetermined control range and activates or deactivates the actuators accordingly. If the temperature or humidity deviates from the specified range, the system automatically turns the control devices on or off to restore the desired conditions, thus ensuring stability within the desired range.

The novelty of this study lies in the application of a microcontroller-based automatic control system that can adjust drying conditions adaptively to maintain temperature and humidity stability using an air heating element. This approach is expected to improve energy efficiency, shorten drying time, and produce more uniform product quality compared to conventional drying systems without automatic control.

Compared to previous studies, the state of the art of this study lies not only in examining the drying process but also in implementing an active control system. Previous studies did not control humidity in real time, whereas this study controls temperature and humidity simultaneously. In other words, this study manages two critical parameters in an integrated manner. This study also goes beyond monitoring by applying automated decision-making through relays, heaters, and blowers.

This study has several limitations that should be acknowledged. The system testing was conducted at a laboratory scale with limited capacity; therefore, its scalability to larger production capacities has not been comprehensively evaluated. In addition, the study does not include a quantitative analysis of energy consumption and efficiency, which prevents a thorough comparison of system performance with other drying methods in terms of power optimization. Economic feasibility, long-term operational costs, and

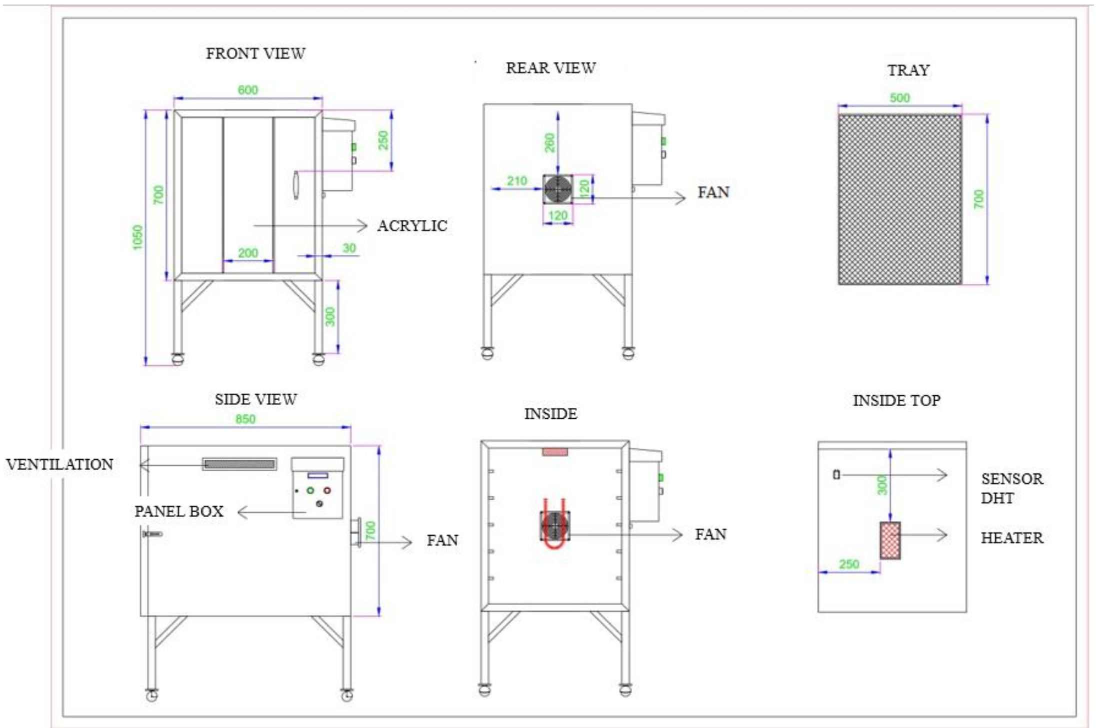

Figure 1. System Design

implementation challenges for small- and medium-scale industries have also not been extensively analyzed. Therefore, further research is required to validate the system under broader operating conditions that more closely represent real industrial applications.

II. Research Method

To clarify the stages of this study, a flowchart was created to systematically illustrate the research process. The diagram shows the sequence of activities, from the initial design stage to the final data analysis stage. Each step in the diagram represents the work process, including the literature review, selection of appropriate components, design and programming of the control system, and testing of the equipment's performance in the drying chamber.

A. System Design and Construction

At this stage, a design plan was prepared to serve as a guide for the equipment installation process. The design was intended to provide a clear visualization of the component layout and the overall system structure. This design supports a more systematic construction process, reduces the potential for installation errors, and ensures that each component is properly connected and functions as intended.

Figure 1 illustrates the design and construction of a sweet potato chip drying machine based on a temperature and humidity control system. Inside the drying chamber, a heating element (heater) is installed at the bottom to generate hot air, while an auxiliary fan is used to accelerate the airflow toward the material being dried [20]. A DHT22 sensor is positioned in the upper interior section to continuously monitor air temperature and humidity in real time during the drying process [21], [22].

In addition, the machine is equipped with drying trays or racks that allow the sweet potato slices to be arranged evenly, which helps ensure uniform exposure to heat and airflow [23]. The component layout shown in the figure is designed to make system installation and maintenance easier, while also minimizing the risk of assembly errors and improving operational reliability [24].

The dimensions of the equipment are 850 cm × 700 cm. This size was chosen to accommodate 2 kg of sweet potato chips during the heating process. In addition, this size allows even airflow distribution without making the chamber excessively large, which could waste energy.

The cabin material consists of wooden planks on the outside and zinc on the inside. These materials were selected because the interior contains a heater. If the interior were made of wood, it could burn when exposed to heat from the heater. Zinc, by contrast, is more heat-resistant.

TABLE 1
MICROCONTROLLER PIN-OUT

Microcontroller Pin	Microcontroller Out
VCC	VCC LCD
GND	GND LCD
A4	SDA LCD
A5	SCL LCD
1	Output Relay 1 (5V)
4	Output Relay 2 (5V)
3	Output DHT22

TABLE 2
DHT22 PIN-OUT

DHT22 Pin	DHT22 Out
VCC	VCC LCD
GND	GND LCD
Pin-Out	Pin 3 Arduino

TABLE 3
RELAY 5V PIN-OUT

Relay Pin	Relay Out
VCC	VCC DHT22
GND	GND DHT22
Out	Pin 2 Arduino

TABLE 4
RELAY 220V PIN-OUT

Relay Pin	Relay Out
Pin 2	NO Relay 5V
Pin 7	Neutral
Pin 8	MCB
Pin 6	Heater

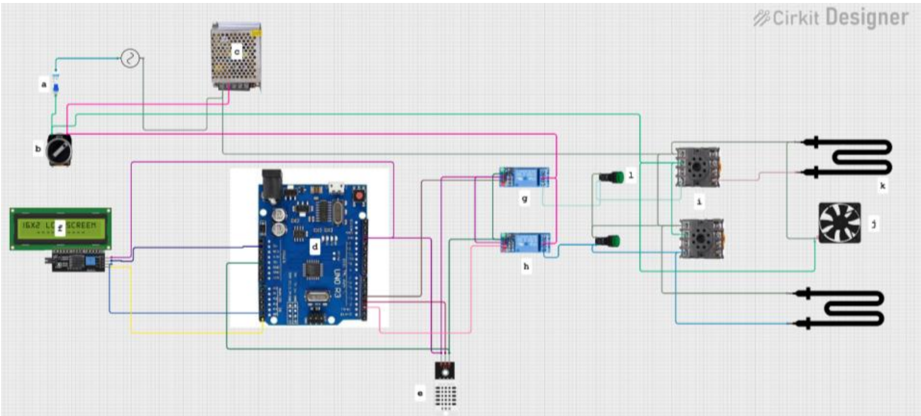

Figure 2. Wiring Diagram

The fan is placed at the center of the side section because it can distribute the hot air generated by the heater throughout the cabin. at the top center so that both the uppermost sweet potato chips and the layers below can receive heat, assisted by the fan, which then circulates the hot air throughout the cabin.

Ventilation openings are located on the right and left sides of the cabin to allow the hot air driven by the fan to circulate properly. The sensor is positioned above the heater because it is used to detect the temperature and humidity inside the cabin. Therefore, it is placed close to the heater, but not too close, to prevent damage caused by excessive heat. Furthermore, zinc is suitable for the specified temperature and humidity range because it is more heat-resistant than wood.

B. Wiring Diagram Design

Before the project begins, this stage starts with the creation of a circuit design that serves as a reference for the system assembly and installation process. The circuit is intended to provide a clear visualization of the system workflow and the relationships among the components used. The circuit design was created using the Circuit Designer platform for the temperature and humidity control system. This design supports a more systematic assembly process, minimizes errors in component connections, and serves as the main guideline for system performance testing. The pin connections for each control component are as Table 1 – 4.

```
#include <LiquidCrystal_I2C.h>
LiquidCrystal_I2C lcd(0x27, 16, 2);

#include <DHT.h>
#define DHTPIN 3
#define DHTTYPE DHT22
DHT dht(DHTPIN, DHTTYPE);

// Pin relay
#define RELAY1Pin  2   // untuk heater utama
#define RELAY2Pin  4   // untuk heater tambahan

void setup() {
  Serial.begin(9600);
  lcd.init();
  lcd.backlight();
  dht.begin();

  // Tampilkan pesan awal
  lcd.setCursor(0, 0);
  lcd.print("CONTROL SUHU DAN");
  lcd.setCursor(0, 1);
  lcd.print("  KELEMBABAN  ");
  delay(5000);
  lcd.clear();

  // Inisialisasi relay
  pinMode(RELAY1Pin, OUTPUT);
  pinMode(RELAY2Pin, OUTPUT);
  digitalWrite(RELAY1Pin, LOW); // mati terlebih dahulu
  digitalWrite(RELAY2Pin, LOW); // mati terlebih dahulu
}

void loop() {
  float temp = dht.readTemperature();
  float hum = dht.readHumidity();

  if (isnan(temp) || isnan(hum)) {
    lcd.setCursor(0, 0);
    lcd.print("ERROR SENSOR");
    lcd.setCursor(0, 1);
    lcd.print("Periksa Koneksi");
    delay(1000);
    return;
  }

  // Tampilkan di serial monitor
  Serial.print("Kelembaban: ");
  Serial.print(hum);
  Serial.print(" %\t");
  Serial.print("Suhu: ");
  Serial.print(temp);
  Serial.println(" C");

  // Tampilkan di LCD
  lcd.setCursor(0, 0);
  lcd.print("Suhu: ");
  lcd.print(temp);
  lcd.print((char)223);
  lcd.print("C   ");
  lcd.setCursor(0, 1);
  lcd.print("Hum: ");
  lcd.print(hum);
  lcd.print("%   ");
  // Delay update layar
  delay(1000);

  // Kontrol suhu dan kelembaban secara bersamaan.
  if (temp >= 55 && hum <= 35){
    // (Matikan semua jika suhu dan kelembaban tercapai)
    digitalWrite(RELAY1Pin, HIGH);
    digitalWrite(RELAY2Pin, HIGH);
  } else if (temp <= 45 && hum >= 40){
    // (Nyalakan semua jika suhu dan kelembaban tercapai)
    digitalWrite(RELAY1Pin, LOW);
    digitalWrite(RELAY2Pin, LOW);
  }
}
```

Figure 3. The Programming on the System

Figure 2 shows the temperature and humidity control system circuit for an Arduino Uno-based sweet potato chip drying machine designed using software. The system consists of several main components interconnected to regulate and monitor temperature and humidity conditions within the drying chamber, including a power supply (c), an MCB (a), and a switch (b) for overcurrent protection. In this circuit, the DHT22 sensor (e) functions to detect the air temperature and humidity inside the drying cabin. Data from the sensor readings are sent to the Arduino Uno microcontroller (d), which serves as the system control center. The microcontroller then processes the data and displays the temperature and humidity values in real-time via LCD (f). Relay modules (g and h) are used as automatic switches to control the heating element (k) and blower fan (j) according to the output signal from the Arduino. These two actuators are connected via a contactor (i) to ensure that the flow of high-power electric current remains safe and stable. Lamps (l) are used as indicators.

Figure 3 is the system programming. The rationale for the electrical design can be seen in the selected power supply. The power supply has sufficient capacity to support the load of all system components, including the Arduino, sensors, relay modules, and actuators. Because the control circuit requires only a small power supply, a 5 V power supply is used. The main power source for the device is PLN (State Electricity Company) because the system requires AC voltage. The Miniature Circuit Breaker (MCB) used is a single-phase MCB, which protects the system from potential overcurrent that could damage the components. The component ratings used are as follows.

1) The DHT22 sensor operates within a voltage range of 3.5 V to 5.5 V, with a current of 0.3 mA, a temperature range of -40°C to 80°C, and a humidity range of 0% to 100%, with an accuracy of +/- 0.5°C and +/- 1% humidity. This sensor was chosen because the desired temperature range is 45–55°C and the desired humidity range is 35%–40%.
2) The relay used is a 5V relay because it matches the power supply used.

Power/control isolation is achieved by separating the power and control lines to avoid interference or potential damage from high currents flowing through the control lines. This is crucial to ensure that the control circuit (Arduino and sensor) remains protected from high-current disturbances caused by the heating element and blower fan. Basic safety considerations include the addition of MCBs and switches, which serve as the first line of protection by cutting off the current in the event of an overload or fault in the electrical system.


(a) (b)

Figure 4. Cabin Installation (a) Panel Box (b) Heat Element.

C. Cabin Installation

The next stage involved the installation of the control panel on the drying machine cabin. The control panel functions as the central control unit that integrates all system components, including the main and auxiliary heating elements [25]. This installation aims to achieve a well-structured and safe electrical configuration while also protecting the components from external disturbances. In addition, installing the control panel is intended to improve the ease of maintenance, monitoring, and control of system performance during the drying process [26].

Figure 4 illustrates the installation of the heating cabin used in this study. On the front side of the cabin, a main control panel is installed, consisting of a power switch, operation indicator lights, and a heater control switch. This panel functions to regulate, monitor, and control the temperature inside the cabin according to the requirements of the heating process.

The heating elements are connected to the control system through neatly arranged electrical wiring installed in the upper section of the cabin to ensure safety and facilitate maintenance. In the upper front section, an air vent is provided to allow air circulation, thereby helping maintain temperature and humidity stability inside the heating chamber [27]. This stage also includes the arrangement of electrical cables and component placement to prevent obstruction of the hot airflow inside the cabin. The installation process is carried out with careful attention to safety standards and technical procedures to ensure the stability and reliability of the heating system during testing.

The decision to install appropriately sized air vents helps ensure good air circulation, which is necessary to maintain stable temperature and humidity inside the cabin. The placement of these vents is designed with attention to the ratio of incoming and outgoing airflow to prevent excessive heat accumulation and ensure optimal drying.

The positioning of the heating elements is also arranged with attention to even heat distribution. The main and auxiliary heating elements are connected to the control system through electrical cables inside the cabin. The exterior of the cabin is made of wood, while the interior is made of zinc. The heating elements do not come into direct contact with the wood, but with the zinc, because wood can burn when exposed to direct heat from the heater. The installation process is carried out in accordance with safety procedures, including the separation of materials that are vulnerable to high temperatures.

D. Testing Procedures

The drying system was then operated under experimental conditions that refer to common drying practices for sliced tuber crops in Indonesia, namely at a temperature of approximately 50°C, with the relative humidity of the drying air maintained within a stable range of 30%–35% RH inside the drying chamber, because this condition is considered optimal for accelerating moisture reduction without degrading the physical quality of the product [28]. These operating conditions were selected to achieve a final moisture content below 10%, which is commonly recommended in the literature for dried tuber-based products to ensure product stability, inhibit microbial growth, and extend shelf life [29].

Figure 5 shows a flowchart of the Arduino programming logic and control algorithm. This diagram explains the process used to control two heaters based on temperature and humidity readings. The process begins by determining whether the process has started. Once the process begins, the system reads the temperature and humidity. The selected temperature threshold range of 45°C–55°C is based on previous research showing that moderate air temperatures of 40°C–70°C are critical operating parameters

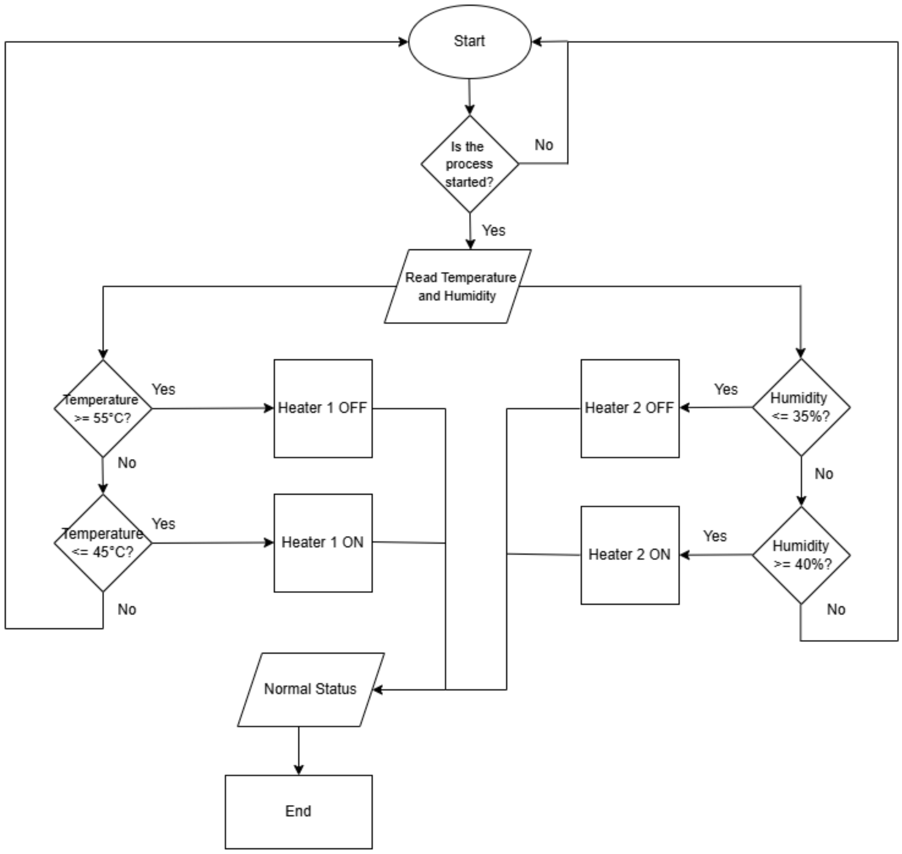

Figure 5. Arduino Programming Logic and Control Algorithms

for effective drying [7]. If the temperature is greater than or equal to 55°C, heater 1 is turned off. If the temperature is less than or equal to 45°C, heater 1 is turned on.

The system then checks the humidity. The humidity threshold was set at 40% because previous research indicated that 40% relative humidity produced the highest drying rates and moisture gradient in sweet potato drying [7]. For humidity control, if the humidity is less than or equal to 35%, heater 2 is turned off. If the humidity is greater than or equal to 40%, heater 2 is turned on. The system then returns to normal status, and the process ends. This flowchart allows real-time adjustment of heating and humidity levels, thereby ensuring optimal conditions based on the predetermined temperature and humidity thresholds.

At this stage, it is important to note that these threshold ranges also take into account the characteristics of the sensors used in the system. The selected temperature and humidity sensors have a measurement accuracy of ±0.5°C and ±2% RH, with an average response time of 2 seconds. This response delay is considered in the decision-making logic to ensure that changes in heating status do not occur too quickly or too slowly, which could affect overall system performance.

III. RESULT AND DISCUSSION

In this study, system testing was conducted using two primary variables: with and without product, and with and without control. These variations were applied to evaluate the effectiveness of the drying system under different operating conditions. The tests conducted with and without product aimed to analyze the thermal characteristics inside the drying chamber, including temperature and humidity distribution, both under load conditions and when the chamber was empty. Meanwhile, the tests conducted with and without control were intended to assess the dynamic response of the system to changes in temperature and humidity, as well as to observe the capability of the control system to maintain stable operating conditions according to the predefined parameters.

Through this approach, a more comprehensive understanding was obtained of the stability, efficiency, and reliability of the temperature and humidity control system in the drying machine, both in terms of thermal performance and the overall stability of the drying process.

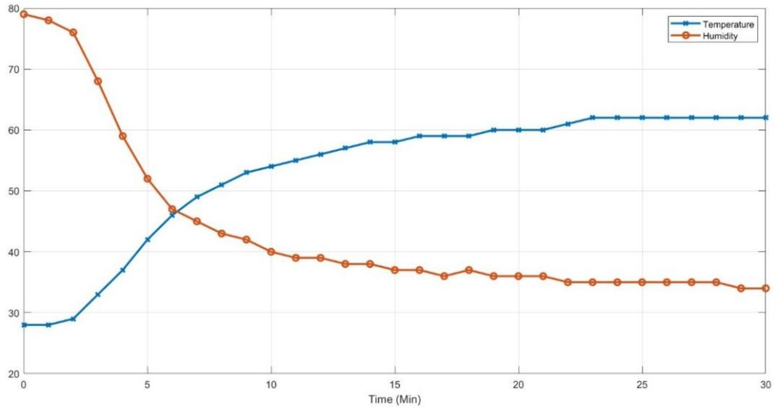

Figure 6. Temperature and Humidity Graph of the Uncontrolled System with Product

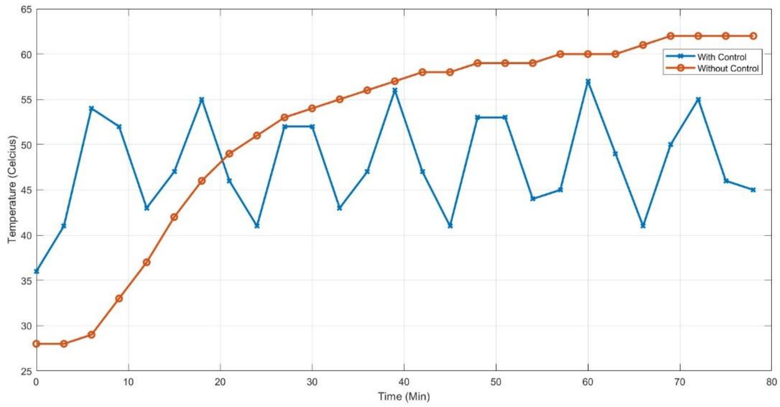

Figure 7. Drying Chamber Temperature Graph with Controlled and Uncontrolled System Variable

A. Control System Testing with Product Variations

The initial test was conducted to evaluate the performance of the drying chamber under conditions in which the system was loaded with product but operated without a control system. The objective of this test was to observe the thermal response and air humidity inside the chamber during the drying process. The observed parameters included variations in temperature and relative humidity over the operating period, allowing the behavior of the drying system to be characterized before the application of automatic control.

Figure 6 illustrates the temperature and humidity variation in the uncontrolled system under load conditions (sweet potato chips). At the beginning of the process, the air temperature was approximately 28°C with a relative humidity of around 80%. Over time, the temperature increased rapidly, reaching 60°C within 20 minutes, and then tended to stabilize. In contrast, the humidity decreased significantly to around 35%. This pattern indicates an inverse relationship between temperature and humidity.

Subsequent testing was conducted by comparing the system response under identical load conditions, namely between the uncontrolled system and the system equipped with a control mechanism. The purpose of this test was to evaluate the effectiveness of the designed control system in maintaining stable air temperature and humidity during the sweet potato chip drying process. Through this comparison, it can be determined to what extent the control system can maintain the process parameters within the desired range or according to the established drying standards.

Based on the drying chamber temperature graph in figure 6, a clear difference in response can be observed between the controlled and uncontrolled systems. In the uncontrolled system, the temperature gradually increased until it reached approximately 60°C. In contrast, in the controlled system, the temperature fluctuated within the range of 40°C to 55°C.

Based on Figure 7, the system response with the controller exhibits greater fluctuations than the uncontrolled system, which appears smoother. This behavior is a natural characteristic of the on-off control strategy implemented with a temperature range of 45°C to 55°C and a humidity range of 35% to 40%. In this method, the heater operates in only two states, ON or OFF. Thus, when the temperature reaches

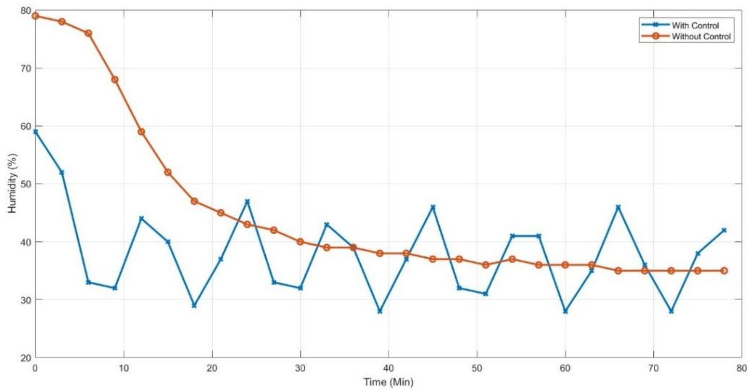

Figure 8. Drying Chamber Humidity Graph with Controlled and Uncontrolled System Variables

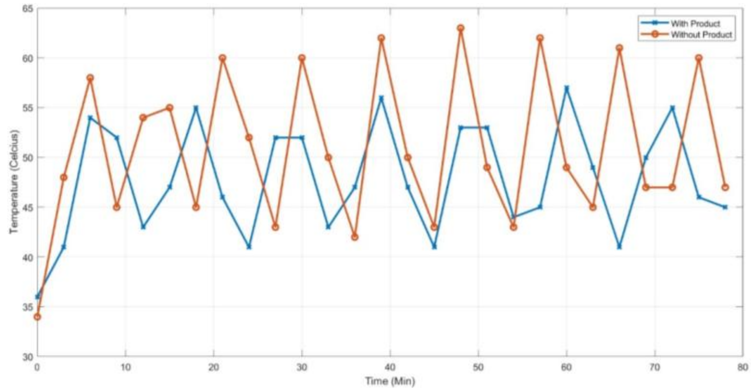

Figure 9. Drying Chamber Temperature Graph with Product and without product System Variables

the lower limit, the heater is activated, and when it reaches the upper limit, the heater is deactivated. This mechanism inherently produces a cyclical rise-and-fall pattern around the setpoint range. In contrast, the uncontrolled system experiences more continuous heating without repeated switching, resulting in a smoother response curve. However, a smoother response does not necessarily indicate better performance because temperature and humidity are not maintained within specific limits. Therefore, the observed fluctuations in the controlled system are a consequence of the applied control strategy and show that the system operates within the predefined operating range.

Meanwhile, the humidity graph in Figure 8 shows a decreasing trend in both the controlled and uncontrolled systems. In the uncontrolled system, the humidity decreased from 80% to approximately 35%. In contrast, in the controlled system, the humidity showed a fluctuating pattern within the range of 30% to 45%. These fluctuations occurred because the control system adjusted the operation of the heating element to maintain temperature stability, which indirectly affected the humidity level inside the drying chamber. These results indicate that the implementation of the control system was able to maintain a balance between temperature and humidity during the drying process, thereby achieving drying conditions closer to the desired state.

Subsequent testing was conducted on the drying chamber equipped with the control system under two operational conditions: with product load and without product load. The objective of this test was to evaluate the performance of the control system under different operating conditions in order to determine the influence of the presence of the product on the system's performance and stability during the drying process.

The figure 9 shows that the drying chamber temperature tended to fluctuate around the control system's setpoint under both conditions, with and without product load. During the drying process, the temperature ranged between 45°C and 60°C. These fluctuations reflect the operation of the control system in maintaining the temperature within the desired range.

Under the condition with product load, the temperature tended to be slightly lower than under the condition without product. This occurred because the product acted as a thermal load and absorbed part of the heat energy during the drying process. Nevertheless, the temperature fluctuation pattern shows that the control system consistently maintained thermal stability within the drying chamber under both conditions.

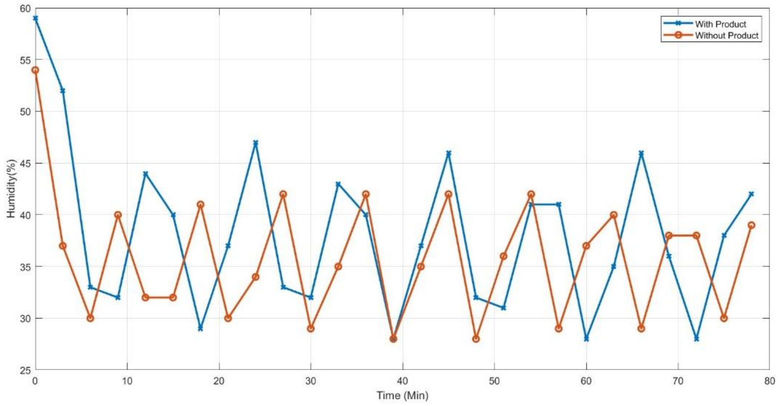

Figure 10. Drying Chamber Humidity Graph with Product and without Product System Variables

Figure 10 shows that the drying chamber humidity fluctuated within the range of 30% to 50% under both conditions, with and without product load. At the beginning of the test, the relative humidity in the presence of the product was slightly higher because of moisture evaporation from the material being dried. Over time, the humidity decreased and fluctuated in response to temperature variations caused by the operation of the control system.

In the temperature graph, both with and without product, the temperature consistently remains within the control range of 45 to 55°C without divergence or an increasing oscillation amplitude, thereby satisfying the bounded-input bounded-output (BIBO) stability criterion. The observed overshoot remains within the designed limits, and the periodic oscillation pattern represents the inherent behavior of the On–Off control strategy. Similarly, in the humidity graph, the values are maintained within the 35 to 45% range after the initial transient phase. The presence of the product, which acts as a thermal load and moisture source, does not cause significant deviation beyond the control limits, indicating good disturbance rejection capability. The consistent fluctuation patterns under both conditions also demonstrate adequate repeatability.

To analyze the performance of the on-off control system, an evaluation can be conducted by reviewing the Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) values based on temperature and humidity measurement data. This analysis was conducted by comparing conditions without control and with control, as shown in Figure 6.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(r_i - y_i)^2} \tag{1}$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|r_i - y_i| \tag{2}$$

The RMSE and MAE formulas are shown in (1) and (2), where r_i is the setpoint and $y_i$is the actual value. The comparison between the measurement data and the reference value is then calculated using the RMSE and MAE parameters. The MAE value indicates the average absolute deviation between the measured value and the setpoint during the control process. Meanwhile, the RMSE value indicates the error level and is more sensitive to large deviations because the error is squared before being averaged. Therefore, RMSE can illustrate large fluctuations that may occur during the control process. The RMSE value for temperature measurement data with control is 5.2, while the MAE value for temperature measurement data with control is 4.6.

The RMSE and MAE values for on-off control are influenced by the setpoint value, which falls within two ranges, causing the system response to oscillate; however, the system can still maintain the sensor reading within the desired setpoint range.

The experimental results indicate that the developed temperature and humidity control system was able to maintain stable drying conditions at approximately 50°C, with a relative humidity of 30% to 35% RH, allowing the moisture content of the product to decrease gradually and in a controlled manner. When compared with previous studies that used oven drying of sweet potato chips at higher temperatures

TABLE 5
CONDITION OF SWEET POTATO BEFORE THE SYSTEM IS TURNED ON

Condition	Moisture Content	Percentage Reduction
Condition 1	40.4 %	68.8 %
Condition 2	39.9 %	80.7 %

TABLE 6
DATA OF MOISTURE CONTENT REDUCTION OVER DRYING TIME

Drying Time	Final Moisture Content
2 hours	12.5
3 hours	7.7

(a) (b)
Figure 11. Results of the Sweet Potato Chip Drying Process (a) The drying process lasted for 2 hours (b) The drying process lasted for 3 hours

of 70°C to 120°C, clear differences in both process characteristics and outcomes can be observed [30]. Although higher drying temperatures were reported to accelerate the drying rate, they also posed a risk of physical degradation, such as surface darkening and excessive shrinkage, particularly at 120°C. In contrast, the present study shows that drying at lower but stably controlled temperatures within the range of 40°C to 55°C results in a more moderate reduction in moisture content, thereby minimizing the risk of physical quality deterioration in the final product.

B. Product Testing Results (Sweet Potato Chips)

The sweet potato drying process using the drying chamber was conducted in two stages: the first test lasted 2 hours, and the second test lasted 3 hours. Both tests were performed using the same product mass to ensure consistent initial drying conditions. The objective of this experiment was to evaluate the performance of the drying chamber in reducing the moisture content of the sweet potatoes to the desired level and to assess the system's effectiveness in maintaining stable temperature and humidity parameters throughout the drying process.

Figure 11 shows the results of moisture content measurements in sweet potato products after the drying process using a digital moisture meter. Image (a) presents the drying result after 2 hours, with a measured moisture content of 12.5%, while image (b) shows the result after 3 hours, with a moisture content of 7.7 %. These results indicate that extending the drying time contributes significantly to moisture reduction, particularly during the final drying stage when bound water begins to be released from the tuber tissue. A moisture content decrease of 4.8% within a one-hour interval shows that the drying conditions at 50°C and 40% relative humidity remained effective in promoting water vapor diffusion from the product to the drying air.

Table 5 shows the moisture content of the sweet potato before the system was turned on. Condition 1 represents the moisture content before the 2-hour drying process, while Condition 2 represents the moisture content before the 3-hour drying process.

Table 6 presents the reduction in product moisture content during the drying process. After 2 hours of drying, the moisture content decreased significantly to 12.5%, and after 3 hours, the final moisture content reached 7.7%. These results indicate that the drying system effectively reduces the moisture content over time and achieved the desired dryness within 3 hours.

These results indicate that the control system contributed to a significant reduction in moisture content. The sample used was 2 kg of sweet potato. The type of sweet potato used was purple sweet potato. The samples used in the 2-hour and 3-hour trials were different fresh sweet potato samples, but each had the same weight of 2 kg. The initial moisture content of the sweet potatoes before heating for 2 hours and 3 hours is shown in Table 5. Details of the cabin temperature and humidity measurements were obtained using a DHT22 sensor placed inside the cabin, while the moisture content of the product was measured using a moisture meter inserted into the sweet potato chip product. The final moisture content values reported for these sweet potato chips were based on single measurements rather than average values. Based on Tables 5 and 6, the percentage of moisture content reduction for each condition can be calculated by (3).

$$\text{Percentage Reduction} = \frac{(Initial\ Water\ Content - Final\ Water\ Content)}{Initial\ Water\ Content} \times 100\% \tag{3}$$

In terms of final product performance, previous research reported that drying sweet potatoes at a higher temperature of around 70°C for approximately 8 hours resulted in a final moisture content of 10.08%. In comparison, this study achieved a final moisture content of 7.7% with a drying time of 3 hours [31]. Other research has shown that drying sweet potatoes at higher temperatures can reduce moisture content to the range of 6% to 7%. However, the lack of humidity control resulted in relatively large variations in moisture content between samples.

In contrast, Figure 11 provides visual documentation of the moisture content measurements and shows lower final moisture content results with shorter drying times, illustrating the trend of moisture reduction under these experimental conditions. However, this comparison across studies is only indicative because of differences in experimental conditions, such as sample preparation, drying settings, and moisture measurement bases. This demonstrates that simultaneous regulation of temperature and relative humidity plays a crucial role in improving drying efficiency and maintaining the stability of the final product moisture content.

IV. CONCLUSION

Based on the results and analysis, it can be concluded that the design of a temperature and humidity control system for a sweet potato chip drying machine using a dual air heater and an Arduino Uno microcontroller was successfully developed under laboratory-scale testing conditions. The system maintained the drying chamber temperature within the range of 45–55°C and relative humidity within approximately 35% to 40% through an automatic switching mechanism between the main and auxiliary heaters. Under these conditions, the moisture content of the product decreased from 39.9% to 7.7% within 3 hours, representing a moisture reduction of approximately 80.7%. When the measured values deviated from the setpoint range, the control system automatically activated the heaters and fan to restore the drying conditions.

Future research is recommended to incorporate comprehensive energy consumption and efficiency analyses to enable a more thorough evaluation of system performance. In the current implementation of on-off control, considerable temperature fluctuations were observed, indicating limited stability in maintaining a consistent temperature. The use of PID or fuzzy logic control may provide a more effective solution to address this issue. Previous research has shown that PID control can provide a fast and precise response, reduce overshoot, and maintain temperature stability within a narrow range [32]. In addition, fuzzy logic control and fuzzy-PID generally offer significant advantages in accuracy, adaptability, and stability [33]. Furthermore, the integration of Internet of Things (IoT)-based remote monitoring, performance testing on various agricultural commodities, and analyses of scalability and economic feasibility for small and medium enterprise (UMKM) implementation are important steps to ensure broader applicability and more sustainable real-world deployment of the system.

DECLARATION OF AI AND AI ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, the author(s) used ChatGPT in order to translate and improve the language quality of the manuscript. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Bobi Khoerun: Conceptualization, Implementation, Resources, Writing-Reviewing and Editing, Formal Analysis, and Project Administration. **Cahyono Putra**: Methodology, Testing, Visualization, and Supervision. **Rahajeng Kurnianingtyas**: Design, Evaluation, and Writing-Original Draft

Preparation.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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