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# Design and Development of Tempe Fermentation Tool Based on Fuzzy Method to Determine Tempe Maturity Level

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**ABSTRACT**

**Purpose of the study:** This study aims to design an innovative tempeh fermentation tool based on the Mamdani fuzzy method that is able to accelerate fermentation and determine the level of tempeh maturity accurately using weight parameters and visual image analysis. This tool is designed to improve the efficiency, productivity, and competitiveness of the tempeh industry by maintaining the quality of tempeh according to standards.

**Methodology:** The results showed that this tool was able to accelerate fermentation with an average time of 21.7 hours, producing quality tempeh with evenly growing fungi without rot. The load cell sensor successfully weighed two tempeh at once with an average weight loss of 10.5 grams, and the ESP32CAM successfully monitored the tempeh visually during fermentation.

**Main Findings:** From the results testing that has been done for 7× shows that tool This succeed speed up fermentation with eat average time 21.7 hours with criteria mold grow even and not rotten and loadcell sensor successful Weigh 2 tempeh at a time fermented with decline average weight 10.5 grams and ESP32CAM successfully monitored tempeh visually at the time fermented.

**Novelty/Originality of this study:** The novelty of this research lies in the integration of DHT11 sensor technology, load cells, and ESP32CAM which enables automatic control of temperature and humidity, real-time monitoring, and accurate determination of tempeh maturity levels. This innovation provides a practical solution to improve the efficiency of the fermentation process and the quality of tempeh production, making it suitable for application on an industrial scale.



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## 1. INTRODUCTION

The growth of food products in Indonesia is increasingly rapid and diverse, which has provided nutrients to a person [1]-[3]. The food consumed has become a concern for the community because some food products are unhygienic or have no nutritional value, so they are at risk of health cases. Indonesia has become the largest soybean market in Asia. As much as 50% of soybean use in Indonesia is used to produce tempeh, then 40% is used to produce tofu and 10% is used to produce tauco, soy sauce and others. The average consumption of tempeh per person per year in Indonesia is predicted to be approximately 6.45 kg. One of the foods that is relatively cheap and has a nutritional content that is almost equivalent to meat, rich in fiber, vitamin B and iron is soybeans found in tempeh. Indonesia, which has become the largest soybean market in Asia today, has produced many Indonesian people who have a source of livelihood as tempeh craftsmen [4]-[6].

Tempeh is a food made from fermented soybeans and tempeh yeast (Rhizopus Oligosporus). The role of yeast is very important because it is the main aspect that supports the success of making tempeh. In order to produce optimal tempeh, it is mandatory to pay attention to the balance of the amount of tempeh yeast to the amount of soybeans to be processed into tempeh. Not only that, the length of fermentation time can be influenced by the high and low room temperatures. Tempeh craftsmen generally still apply the manual tempeh fermentation process, namely by leaving the tempeh in a room with air gaps, if the temperature feels cold, the tempeh is then covered with a cloth to obtain the appropriate temperature, but this process will take quite a long time. The tempeh fermentation process takes 18-48 hours, the speed or length of the fermentation process is influenced by several aspects, namely temperature and humidity. A good fermentation temperature is at room temperature 30-37ºC in a room with oxygen and humidity conditions influenced by the length of fermentation [7]-[9].

Current technology has experienced very rapid development, for example with the many tools that can help humans in lightening work automatically. One of the tools that can help human work is to help tempeh craftsmen in carrying out the tempeh fermentation process automatically by utilizing Arduino as a microcontroller to be more efficient and optimal compared to the manual process. There is a study conducted by entitled "Prototype of Temperature and Humidity Control and Determining Maturity According to the Thickness of Fungal Growth in the Tempeh Fermentation Process Based on Arduino UNO" using the DHT11 sensor, Ultrasonic and 12V DC Fan, the difference with this study is that the author uses a loadcell sensor to determine the maturity of tempeh based on weight, then uses ESP32CAM to determine the maturity of tempeh based on visual images and uses the fuzzy mamdani method as a determinant of the life and death of the fan and lights from the DHT11 sensor reading [10]-[12].

The fuzzy mamdani method is a method used to map problems with the idea of how to find a solution that is unclear or gray from the expected input and output. Based on the research conducted Insantama & Suprianto, [13] entitled "Automatic Water Level Control Design in Tanks with Servo Valves Based on Fuzzy Logic Controllers Using Arduino", in this study fuzzy logic is used as a water level controller so that it can regulate or protect the water level so that it is always normal. Conversely, if in conventional system control it can cause a shortage of water supply when the production process is carried out in large quantities. In this study the author uses loadcell and ESP32CAM, which are used to detect the weight of a load and visual images around it to make it easier to determine the maturity of tempeh in the fermentation process compared to using ultrasonic sensors to determine maturity based on the thickness of the tempeh because there will be inaccuracies in determining the maturity of tempeh such as for example tempeh does not grow evenly or ultrasonic does not detect tempeh accurately while using loadcell and ESP32CAM to determine the maturity parameters in tempeh can be determined based on weight and visual images [14]-[16] .

In previous studies, the fuzzy logic method was used to control the water level to keep it normal. The study emphasized the control of physical parameters in the form of water height in the tank. This study shows the advantages of fuzzy logic in handling uncertain conditions compared to conventional systems, especially to maintain efficiency and prevent water shortages during the production process [17], [18]. However, the application of fuzzy logic in this study has not explored the potential in more complex processes such as fermentation, which involves more dynamic and uncertain parameters. Therefore, there is a research gap in applying the fuzzy logic method to systems that require different combinations of parameters, such as weight and visual, which are directly related to determining the level of maturity in the fermentation process.

Insantama and Suprianto's research focuses on controlling one physical parameter, namely the water level in the tank, using the fuzzy logic method. This study expands the scope by controlling two parameters at once, namely weight through a loadcell sensor and vision through ESP32CAM, which creates a more complex system. This approach allows multi-aspect data processing to determine the level of tempeh maturity more accurately, making the tempeh fermentation process more sophisticated and effective than simple control as in previous studies. In terms of innovation, this study offers a new solution by utilizing a combination of fuzzy logic and weight and visual sensor technology to determine the level of tempeh maturity. This approach overcomes the limitations of conventional methods that rely on one type of sensor, such as ultrasonic, which is prone to inaccuracy [19]-[21]. With advantages in accuracy and efficiency, this study makes a significant contribution to the development of artificial intelligence-based tempeh fermentation technology, as well as being a step forward in the application of fuzzy logic to more complex fermentation processes .

This research presents a novelty by developing a fuzzy method-based control system that integrates two main parameters, namely weight using a loadcell sensor and visual using ESP32CAM. This combination allows for more complex and accurate multi-aspect analysis in determining the level of tempeh maturity, surpassing previous approaches that only focus on one parameter or use ultrasonic sensors that are often less accurate, especially when tempeh does not grow evenly. The application of fuzzy logic to the tempeh fermentation process is also a significant innovation, considering that this method was previously only used to control simple physical parameters, such as water levels [22], [23]. By utilizing modern sensor technology that is able to detect changes in weight precisely and capture visual data in detail, this research provides an effective solution to the challenge of accuracy in the fermentation process. In addition, the integration of fuzzy logic with weight and visual sensors produces an intelligent tempeh fermentation system based on artificial intelligence (AI). This approach not only improves accuracy and efficiency, but also makes a significant contribution to the development of more modern, adaptive, and high-quality fermentation technology to support innovation in the technology-based food industry [24], [25].

This research has important implications in the field of food technology, especially in the tempeh fermentation process. By integrating the fuzzy logic method and modern sensor technology (loadcell and ESP32CAM), the fermentation tool developed can provide more accurate results in determining the level of tempeh maturity. This will help tempeh producers improve product quality consistently, reducing the risk of errors caused by manual observation or imprecise tools [26]-[28]. In addition, this tool can be the basis for further development in artificial intelligence (AI)-based fermentation process automation, which can be applied to various other types of fermented food products. On an industrial scale, this system has the potential to increase the efficiency of production time and costs, as well as support technological innovation in the local and global food industry.

This research is urgently needed because the need for technological innovation in the tempeh fermentation process is increasing, along with the high demand for high-quality tempeh products in the local and international markets. Conventional methods that are still widely used, such as manual observation or simple tools, often result in inaccuracies in determining the maturity of tempeh, thus potentially reducing product quality [29]-[31]. On the other hand, previous studies have not explicitly integrated fuzzy logic with weight and visual sensors for the fermentation process. Therefore, this study offers a relevant and reliable technological solution to increase the competitiveness of tempeh products amidst the development of a modern technology-based food industry. This urgency is also driven by the importance of developing smarter, more efficient, and technology-based fermentation tools, to support the sustainability of an innovative local food industry [32], [33].

This study aims to design and develop an innovative tempeh fermentation tool to overcome the problem of the long fermentation time which is still carried out conventionally. This tool is designed to accelerate the fermentation process, so that it not only increases time efficiency but also provides convenience for tempeh producers in managing their production process. In addition, this study also aims to present a technology that is able to determine the level of tempeh maturity accurately using weight parameters and visual image analysis. With this technology, tempeh producers can ensure the quality of the products produced according to the desired standards. Furthermore, this tool is expected to be a breakthrough in the development of traditional food technology that supports increased productivity, efficiency, and competitiveness of the tempeh industry, both locally and globally [34]-[36].

## 2. RESEARCH METHOD

The first stage is a literature study that aims to examine relevant theories as a basis for planning and designing the system. Furthermore, interviews were conducted to collect data and learn how to make good and correct tempeh at the research location. After that, problem identification was carried out to determine the problems that arose based on the results of interviews and data collection. The next stage is design, which includes making a tool flow diagram, schematic circuit, tool design, and collecting the necessary components. After the design is complete, implementation is carried out in the form of making a tempeh fermentation tool [37]-[39]. The tool that has been made is then tested to ensure its performance is running well. The analysis stage is carried out to examine the effect of temperature on fermentation time and results and to compare automatic and manual fermentation methods. As a final step, all of these stages are summarized in writing a report to complete this thesis.

The research procedure in the application of the design and construction of a tempeh fermentation tool using the fuzzy method to determine the level of maturity of tempeh includes a research procedure that can beseen in the following figure [40]-[42]. In Figure 1 there is a procedure carried out in this study. The research procedure begins with a literature study aimed at finding references relevant to this study then continued with interviews aimed at collecting data and learning how to make tempeh properly at the interview location, after the interview is completed then the problems faced can be identified. Then continued with the design in the form of making a flow diagram, circuit and design of the tools that will be used and will be implemented in making the tool, then testing of all components will be carried out in order to find out whether all components are working properly or not, then it will be analyzed and discussed from each test by knowing the temperature and humidity when the tempeh is fermented and knowing the decrease in tempeh weight when fermented until the tempeh is cooked and then comparing the fermentation time and maturity of the tempeh by fermenting using tools and manual fermentation

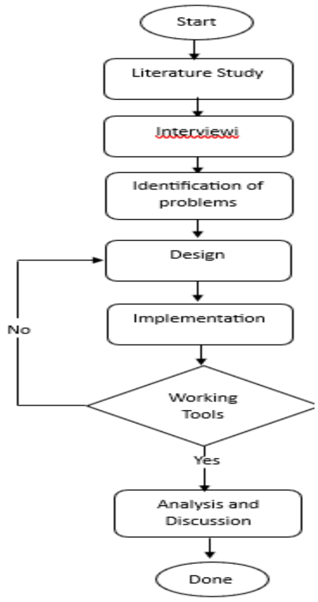

Figure 1. Research Procedure

The process of making tempeh in the design of the implementation of the design of the tempeh fermentation tool using the fuzzy method to determine the level of maturity of the tempeh, there is a procedure for making tempeh which can be seen in Figure 2 as follows.

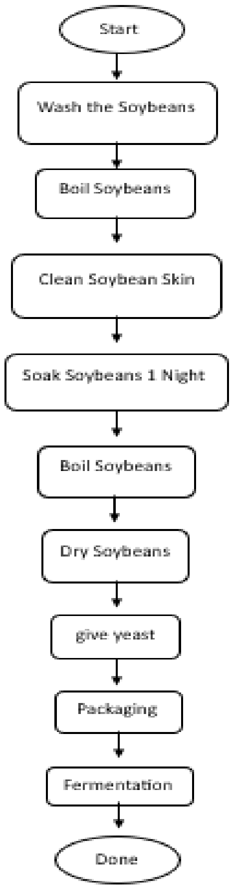

Figure 2. Tempeh Making Process

The tools and materials used in this study were designed to support the design and manufacture of innovative tempeh fermentation tools. The tools used include a laptop for programming and analysis, a screwdriver (+ and -) for component installation, a test pen for testing electric current, combination pliers for mechanical purposes, a soldering iron for connecting electronic components, and a drill for drilling or assembling certain parts. Meanwhile, the main materials include Arduino Uno as a microcontroller, a DHT11 sensor for detecting temperature and humidity, a Loadcell sensor for weight measurement, an HX711 module for reading data from the Loadcell sensor, and an LCD for displaying information. Other components include a 12V incandescent lamp and a 12V fan as a temperature regulator, a TIP122 transistor as a signal amplifier, a 1k resistor for a current controller, tin for connecting components, and a 30A power supply as the main power source. All of these tools and materials were carefully selected to ensure the successful implementation of the designed tempeh fermentation tool. In designing a good tool, steps are needed in the form of designing a tool flow diagram, designing a system block diagram, designing a schematic circuit, designing a tool design and designing a fuzzy mamdani method.

The tool flow begins with reading the DHT sensor and load cell sensor, then the values from the two sensors will be displayed on a 16x2 LCD. After that there are several DHT sensor conditions that will produce output with the operation of the lights and fans. The first condition, if the DHT detects a low temperature with a temperature range of 29-31ºC, the lights will be bright and the fan will be slow. The second condition, if the DHT detects a moderate temperature with a temperature range of 32-34ºC, the lights will be bright and the fan will be moderate. The third condition, if the DHT detects a high temperature with a temperature range of 35-37ºC, the lights will be dim and the fan will be fast.

. Starting from the 12V Power Supply used as a power supply to the Arduino Uno, 12V Lamps and Fans, then there is a DHT Sensor and a loadcell Sensor that will send data to the Arduino Uno then the values from the two sensors will be displayed on the LCD as a monitor media. Furthermore, there is a Switching Circuit used as a controller for the Lamp and Fan in the form of PWM output via input from the DHT Sensor managed by the Arduino Uno.

The schematic circuit used in this study can be seen in Figure 5 as follows.

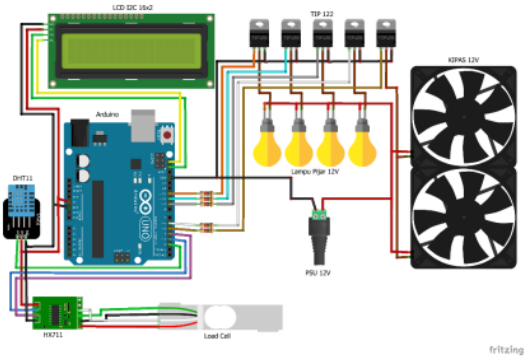


Figure 3. Schematic Circuit

In Figure 3 there is a schematic circuit used in this study. The author uses Arduino Uno as a microcontroller of all connected components, then there is a DHT sensor as a temperature and humidity detector in the fermentation room, then there is a loadcell sensor and HX711 module as a weight of tempeh when fermented, then there is a TIP122 transistor used as a switching connected to the lights and fans, where the lights and fans will work based on input from the DHT sensor, the lights themselves function as heaters and fans as coolers in the fermentation room and there is an LCD used as a monitor of the DHT sensor values, loadcells and PWM from the lights and fans.

The design of the tool used in this study can be seen in Figure 4 and Figure 5 as follows.

Figure 4. Front View of Tool Design

Figure 5. Top View of Tool Design

In Figures 4 and 5 there is a design of the tool used in this study which shows the shape of the tool and the placement of the components. The design used resembles a box with a height of 35 cm and a width of 55 cm which is designed in 3D using Solidworks software.

The fuzzy method design used in this study is fuzzy mamdani which is made using matlab software. The fuzzy mamdani method is implemented into the DHT sensor which will produce the output of the lights and fans. The fuzzy mamdani method design can be seen in Figure 6 as follows.

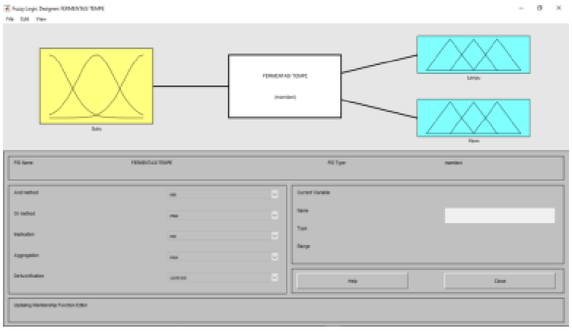

Figure 6. Design of Mamdani Fuzzy Method

Based on the design of the fuzzy mamdani method that has been made, there is a temperature variable used. The following is a graph and the fuzzification process of the temperature variable can be seen in Figure 7 as follows.

Figure 7. Temperature Fuzzification Graph

$$\mu Low(x) = \begin{cases} 1, & x \leq 32 \\ \frac{32-x}{32-31.5}, & 31.5 \leq x \leq 32 \\ 0, & x \geq 32 \end{cases} \quad \ldots(1)$$

$$\mu Medium\,(x) = \begin{cases} \frac{x-31.5}{32-31.5}, & 31.5 \leq x \leq 32 \\ 1, & 32.8 \leq x \leq 3.33 \\ \frac{34.5-x}{34.5-34}, & 34 \leq x \leq 34.5 \\ 1, & x \geq 31.5\ x \geq 34.5 \end{cases} \quad \ldots(2)$$

$$\mu High(x) = \begin{cases} 0, & x \le 34 \\ \frac{x-34}{34.5-34}, & 34 \le x \le 34.5 \\ 1, & x \ge 35 \end{cases} \quad ...(3)$$

Based on the design of the fuzzy mamdani method that has been made, there is a lamp variable that is used. The following is a graph and fuzzification process of the lamp variable can be seen in Figure 8 as follows.

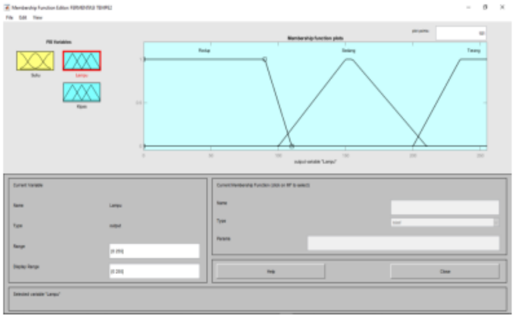

Figure 8. Light Fuzzification Graph

$$\mu Dim(x) = \begin{cases} 1, & x \le 90 \\ \frac{110-x}{110-100}, & 100 \le x \le 110 \\ 0, & x \ge 110 \end{cases} \quad ...(4)$$

$$\mu Medium(x) = \begin{cases} \frac{x-100}{110-100} & 100 \le x \le 110 \\ 1, & 150 \le x \le 155 \\ \frac{210-x}{210-200} & 200 \le x \le 210 \\ 1, & x \le 100 \; x \ge 210 \end{cases} \quad ...(5)$$

$$\mu Bright(x) = \begin{cases} 0, & x \le 200 \\ \frac{x-200}{210-200}, & 200 \le x \le 210 \\ 1, & x \ge 235 \end{cases} \quad ...(6)$$

Based on the design of the fuzzy mamdani method that has been made, there is a fan variable that is used. The following is a graph and the fuzzification process of the fan variable can be seen in Figure 11 as follows.

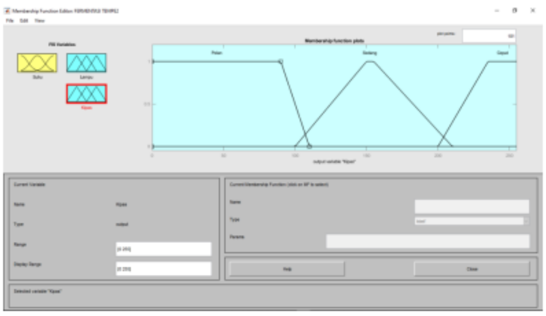

Figure 9. Fan Fuzzification Graph

$$\mu Slow(x) = \begin{cases} 1, & x \le 90 \\ \frac{110-x}{110-100}, & 100 \le x \le 110 \\ 0, & x \ge 110 \end{cases} \quad ...(7)$$

$$\mu Medium(x) = \begin{cases} \frac{x-100}{110-100} & 100 \le x \le 110 \\ 1, & 150 \le x \le 155 \\ \frac{210-x}{210-200} & 200 \le x \le 210 \\ 1, & x \le 100 \; x \ge 210 \end{cases} \quad ...(8)$$

$$\mu Fastt(x) = \begin{cases} 0, & x \le 200 \\ \frac{x-200}{210-200}, & 200 \le x \le 210 \\ 1, & x \ge 235 \end{cases} \quad ...(9)$$

After fuzzification, the next step is the formation of fuzzy knowledge in the form of rules formed to express the relationship between input and output. The rule base can be seen in Table 1 and Figure 12 as follows.

Table 1. Rule Base

| No | Input | Output | |
|---|---|---|---|
| | Temperature | Lamp | Fan |
| 1 | Low | Bright | Slow |
| 2 | Medium | Bright | Medium |
| 3 | High | Bright | Fast |

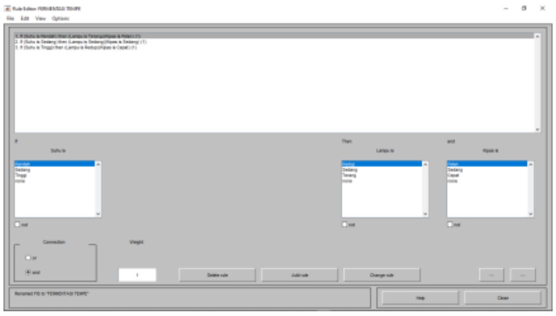

Figure 10. Matlab Rule Base

In this study, researchers designed three main test plans to support the success of the study. First, the DHT11 sensor test was carried out to detect the ambient temperature during the fermentation process. This sensor functions as an input to control the lights and fans using the Mamdani fuzzy method, so that it can ensure optimal temperature conditions during fermentation. Second, testing was carried out on the loadcell sensor and ESP32CAM to determine the level of tempeh maturity based on weight and visual images. In addition, other supporting components, such as LCD, incandescent lamps, fans, buzzers, and power supplies, were also tested to ensure that all parts of the tool worked well and supported the fermentation process. Third, overall testing of the application of the tempeh fermentation tool using the Mamdani fuzzy method was carried out to assess the effectiveness of the tool in accelerating the fermentation process compared to conventional methods. Through this series of tests, it is hoped that the designed fermentation tool will be able to provide more efficient and quality results.

## 3. RESULTS AND DISCUSSION

### 3.1. Implementation

Implementation of the Design and Construction of Tempe Fermentation Equipment Using the Fuzzy Method to Determine the Level of Tempe Maturity is carried out to analyze all the components used in order to find out whether they can work well according to the function and specifications of the components used by testing each component. The DHT11 sensor test was carried out to determine whether it can operate properly according to its function. The function of the DHT11 sensor in this tempeh fermentation tool is very important, namely it is used to detect the temperature in the fermentation room where the DHT11 sensor is used as input to turn on the lights and fans using the fuzzy mamdani method. The DHT11 sensor test can be seen in Figure 13 as follows.


Figure 11. DHT11 Sensor Testing

In Figure 11 there is a test of the DHT11 sensor placed inside the tempeh fermentation tool by detecting temperature and humidity whose values are displayed on the LCD and comparing them with a hygrometer. The comparison can be seen in Table 2 as follows.

Table 2. Comparison Results of DHT11 Sensor with Hygrometer

| O'clock | Sensor DHT11 | | Higrometer | | Eror(%) | |
|---|---|---|---|---|---|---|
| | Temperature (°C) | Humidity (%) | Temperature (°C) | Humidity (%) | Temperature (°C) | Humidity (%) |
| 07.00 - 08.00 | 29.5 - 32.1 | 82 - 72 | 28.7 - 30.3 | 72 - 69 | 2.7 - 5.9 | 13.8 - 4.3 |
| 09.00 - 10.00 | 32.5 - 32 | 71 -72 | 30.4 - 30.2 | 71-72 | 6.9 - 5.9 | 0 - 0 |
| 11.00 - 12.00 | 29.9 - 31.5 | 80 - 75 | 29.8 - 29.9 | 60 -70 | 0.3 - 5.3 | 33.3 - 7.1 |
| 13.00 - 14.00 | 31.7 - 31.8 | 72 - 71 | 30.1 - 30.2 | 70 - 69 | 5.3 - 5.2 | 2.8 - 2.8 |
| 15.00 - 16.00 | 32 - 31.6 | 71 - 70 | 30.1 - 30.4 | 66 - 65 | 6.3 - 3.9 | 7.5 - 7.6 |
| 17.00 - 18.00 | 32.5 - 32.7 | 68 - 69 | 30.9 - 32 | 67 - 68 | 5.1 - 2.1 | 1.4 - 1.4 |
| 19.00 - 20.00 | 32.8 - 32.1 | 69 - 68 | 30.8 - 31.2 | 68 - 69 | 6.4 - 2.8 | 1.4 - 1.4 |
| 21.00 - 22.00 | 33 - 33.3 | 67 - 74 | 31.3 - 31.4 | 69 - 71 | 5.4 - 6 | 2.8 - 4.2 |
| 23.00 - 00.00 | 33.5 - 31.6 | 72 - 71 | 31.4 - 31.6 | 71 - 71 | 6.6 - 0 | 1.4 - 0 |
| 01.00 - 02.00 | 32.5 - 32.8 | 71 - 73 | 30.8 - 31.1 | 71 - 71 | 5.5 - 5.4 | 0 - 28 |
| 03.00 - 04.00 | 30.8 - 31.1 | 72 - 79 | 29.5 - 30.3 | 72 - 71 | 4.4 - 2.6 | 0 - 11.2 |
| 05.00 | 31.7 | 75 | 30.6 | 71 | 3.5 | 5.6 |

Table 2 shows a comparison between the DHT11 sensor and the hygrometer obtained during the tempeh fermentation process carried out for 22 hours. Based on the comparison data, there is the largest error value of 33.3% and the smallest is 0%.

Loadcell sensor testing is carried out to determine whether it can operate properly according to its function. The function of the loadcell sensor on this tempeh fermentation tool is very important, namely it is used to weigh the weight of tempeh during fermentation. Loadcell sensor testing can be seen in Figure 14 as follows.

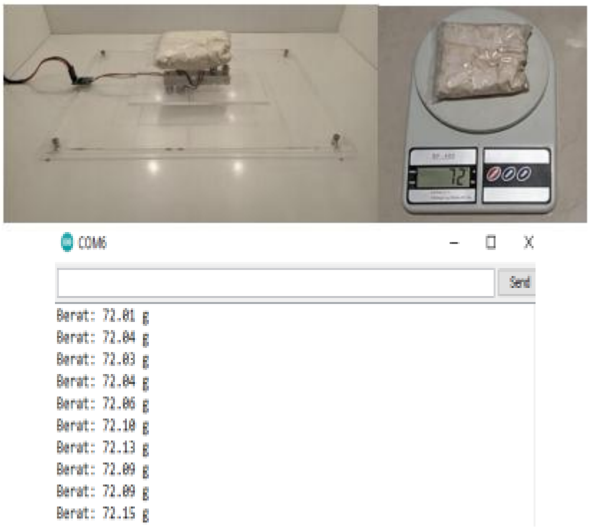


Figure 12. Loadcell Sensor Testing

In Figure 12 there is a load cell test placed at the bottom of the tempeh fermentation tool by weighing the weight of the tempeh whose value is displayed on the serial monitor on the Arduino IDE software and comparing it with a digital scale. The comparison can be seen in Table 3 as follows.

Table 3. Comparison Results of Loadcell Sensors with Digital Scales

| O'clock | Sensor *Loadcell* (Weight - gr) | Digital Scales (Weight - gr) | *Error* (%) |
|---|---|---|---|
| 07.00 - 08.00 | 170 - 170 | 171 - 171 | 0,5 - 0,5 |
| 09.00 - 10.00 | 170 - 170 | 171 - 171 | 0,5 - 0,5 |
| 11.00 - 12.00 | 170 - 170 | 171 - 171 | 0,5 - 0,5 |
| 13.00 - 14.00 | 168 - 168 | 169 - 169 | 0,5 - 0,5 |
| 15.00 - 16.00 | 168 - 168 | 169 - 169 | 0,5 - 0,5 |
| 17.00 - 18.00 | 168 - 168 | 169 - 169 | 0,5 - 0,5 |
| 19.00 - 20.00 | 168 - 167 | 169 - 169 | 0,5 - 0,5 |
| 21.00 - 22.00 | 166 - 165 | 167 - 167 | 0,5 - 0,5 |
| 23.00 - 00.00 | 166 - 164 | 167 - 164 | 0,5 - 0,6 |
| 01.00 - 02.00 | 163 - 161 | 163 - 161 | 0,5 - 0,6 |
| 03.00 - 04.00 | 160 - 160 | 161 - 161 | 0,6 - 0,6 |
| 05.00 | 159 | 160 | 0,6 |

Table 3 shows a comparison between the load cell sensor and the digital scale obtained during the tempeh fermentation process carried out for 22 hours. The weight value obtained is the result of combining 2 tempeh with a weight of 1 tempeh of 85 grams. Based on the comparison data, there is a weight difference of 1 gram where the load cell sensor detects a weight of 1 gram less than the digital scale.

ESP32CAM testing is carried out to determine whether it can operate properly according to its function. The function of ESP32CAM in this tempeh fermentation tool is very important, namely it is used to monitor the mass of tempeh growth visually during fermentation in real time. ESP32CAM testing can be seen in Figure 13 as follows.

Figure 13. ESP32CAM testing

In Figure 13, there is a test of the ESP32CAM which is placed on the top of the tempeh fermentation tool using a box as a place to place the ESP32CAM which can operate well and the EPS32CAM successfully monitors the fermented tempeh with the presence of visual capture results which are 25cm from the ESP32CAM with a resolution of 1600x1200.

LCD testing is carried out to determine whether it can operate properly according to its function. The function of the LCD on this tempeh fermentation tool is very important, namely it is used to monitor temperature, humidity, weight and PWM lights and fans. LCD testing can be seen in Figure 14 as follows.


Figure 14. LCD testing

In Figure 14, there is a test of the LCD placed at the front of the tempeh fermentation tool which can operate well and the LCD successfully displays characters in the form of sentences.

The incandescent lamp test is carried out to determine whether it can operate properly according to its function. The function of the incandescent lamp in this tempeh fermentation tool is very important, namely it is used as a heater in the fermentation room. The incandescent lamp test can be seen in Figure 17 as follows.

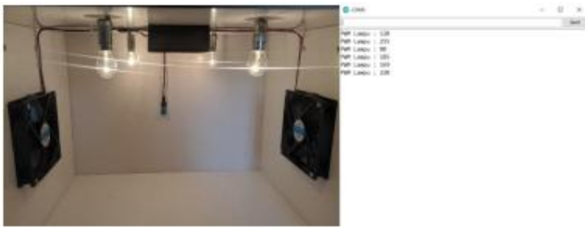

Figure 15. Incandescent Lamp Testing

In Figure 15, there is a test of incandescent lamps with a total of 4 lamps placed on the top of the tempeh fermentation tool. This can operate well and the incandescent lamps successfully heat the fermentation room which is controlled using the PWM output displayed on the serial monitor in the Arduino IDE software.

Fan testing is done to find out whether it can operate properly according to its function. The function of the fan in this tempeh fermentation tool is very important, namely it is used as a cooler in the fermentation room. Fan testing can be seen in Figure 16 as follows.

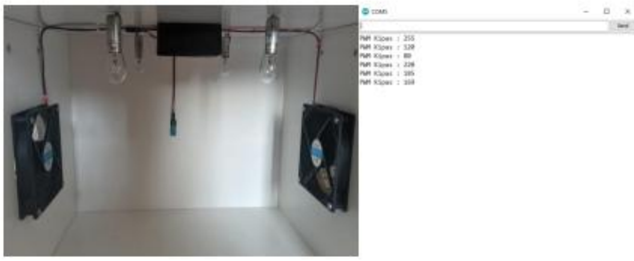

Figure 16. Fan Testing

In Figure 16, there is a test of incandescent lamps with a total of 4 lamps placed on the side of the tempeh fermentation tool which can operate well and the fan successfully cools the fermentation room which is controlled using the PWM output displayed on the serial monitor in the Arduino IDE software.

Buzzer testing is carried out to determine whether it can operate properly according to its function. The function of the buzzer on this tempeh fermentation tool is very important, namely it is used as an alarm when the tempeh is finished being fermented. The buzzer test can be seen in Figure 17 as follows.

Figure 17. Buzzer Testing

In Figure 17 there is a buzzer test by controlling the buzzer to turn on and off. There is a display of buzzer information on the serial monitor in the Arduino IDE software.

Power supply testing is done to find out whether it can operate properly according to its function. The function of the power supply on this tempeh fermentation tool is very important, namely it is used to turn on all components in this tempeh fermentation tool. Power supply testing can be seen in Figure 18 as follows.

Figure 18. Power Supply Testing

In Figure 18 there is a power supply test connected in parallel with a multitester to determine the output voltage issued by the power supply. The maximum and minimum voltages issued by the power supply can be seen in Table 4 as follows.

Table 4. DC Power Supply Voltage Capacity

| Maxsimum | Minimum |
| --- | --- |
| 14.70 V | 10.60 V |

In Table 4 there is a DC voltage capacity issued by the power supply. To turn on all components, a voltage of 12 V is needed so that the components work optimally and if the voltage used is 10.60 V, the components cannot work optimally.

Fuzzy mamdani testing is carried out to determine whether it can operate properly according to its function. The function of fuzzy mamdani in this tempeh fermentation tool is very important, namely it can control lights and fans using the method implemented in the DHT11 sensor. The comparison is simulated using matlab software which can be seen in Figure 19 as follows.

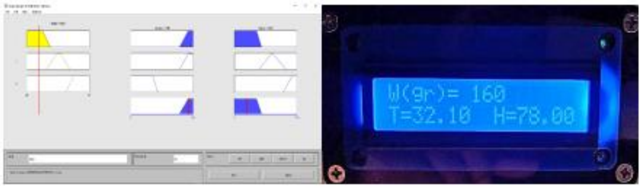


Figure 19. Mamdani Fuzzy Testing

In Figure 19 there is a fuzzy mamdani test using matlab software. Fuzzy mamdani testing is done by entering a temperature value of 32.10 and producing an output in the form of a lamp PWM of 155 and a fan of 155 and comparing the calculations between the microcontroller and matlab software which can be seen in Table 5 as follows.

Table 5. Comparison Results of Fuzzy Mamdani Calculations

| No | Input Mikrokontroler | Input Matlab | Output Mikrokontroler | Output Mikrokontroler | Output Matlab | Output Matlab | Error % | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | Temperature (°C) | Temperature (°C) | Lamp | Fan | Lamp | Fan | Lamp(%) | Fan (%) |
| 1 | 30,60 | 30,60 | 234,8 | 50 | 236 | 49,5 | 0,50 | 1,01 |
| 2 | 32,10 | 32,10 | 155 | 155 | 155 | 155 | 0 | 0 |
| 3 | 31,90 | 31,90 | 167 | 125 | 167 | 125 | 0 | 0 |
| 4 | 34,50 | 34,50 | 52,54 | 231,6 | 51,9 | 234 | 1,23 | 0,17 |
| 5 | 36,70 | 36,70 | 50,17 | 234,89 | 49,5 | 235 | 1,35 | 0,47 |
| 6 | 33,90 | 33,90 | 155 | 155 | 155 | 155 | 0 | 0 |
| 7 | 34,10 | 34,10 | 51,1 | 233,7 | 50,5 | 234 | 1,18 | 0,14 |
| 8 | 37,00 | 37,00 | 50,17 | 234,89 | 49,5 | 235 | 1,35 | 0,47 |
| 9 | 35,80 | 35,80 | 50,17 | 234,89 | 49,5 | 235 | 1,35 | 0,47 |
| 10 | 34,80 | 34,80 | 51,1 | 233,7 | 50,5 | 234 | 1,18 | 0,12 |

In Table 5 there is a comparison of fuzzy mamdani calculations between microcontrollers and matlab software. The comparison was carried out for 10x with the largest error value of 1.35% and the smallest of 0%. In Table 5 there is a comparison of fuzzy mamdani calculations between microcontrollers and matlab software. The comparison was carried out for 10x with the largest error value of 1.35% and the smallest of 0%.

In Figure 20 there is a test of the entire tool starting from the power supply providing power supply to the Arduino, switching circuits and lights and fans. Arduino manages data from reading the load cell sensor and

DHT11 sensor which will then be displayed on the LCD and also controls the lights and fans using fuzzy mamdani calculations.

Figure 20. Overall Testing

### 3.2. Percentage Error Formula

In determining the percentage of error in comparisons in testing, there is a formula used, namely as follows.

$$\%Error = \left|\frac{x - xi}{xi}\right| x\ 100 \qquad ....(10)$$

In the percentage error formula used to obtain the error value in the form of a percentage in comparing one input to another input and one output to another output. The description of the formula contains $X$ is the actual value or real value and $Xi$ is the measured value or value of the tool.

### 3.3. Research Data

Research data from the Design and Construction of Tempe Fermentation Tools Using the Fuzzy Method to Determine the Level of Tempe Maturity includes a comparison between fermentation using tools with manual fermentation and continued with research on the tools carried out for 7 times and the results of testing the tools will be analyzed.

In the study comparing fermentation using tools with manual fermentation starting at 07.00 and ending at 05.00 the next day, thus obtaining a total fermentation time of 22 hours. The fermentation process is shown in Figure 22 as follows.

a b

Figure 21. Fermentation Process a. Using Tools b. Manual

In Figure 21 there is a comparison of the fermentation process using a tool placed on acrylic on the tool with manual fermentation placed on a net. In this comparison, the author used 2 packs of tempeh fermented using the tool and 1 pack of tempeh fermented manually with an initial weight of each tempeh of 85 gr and an estimated final weight of 80-75 gr. The results of the tempeh from this comparison can be seen in Figure 23 as follows.


a b

Figure 22. Fermentation Results a. Using Tools b. Manual

In Figure 22 there are fermentation results using tools and manually. Fermentation using tools takes 22 hours with the criteria that the tempeh has grown evenly and smells normal or not rotten with a weight loss of 2 tempeh of 11 grams and manual fermentation takes 27 hours with the criteria that the tempeh sweats, the fungus does not grow evenly and smells normal or not rotten. The comparison of the tempeh weight loss process during fermentation can be seen in Table 6 as follows.

Table 6. Weight Loss of Fermented Tempeh Using Tools and Manually

| O'clock | Using Tools | Manual |
|---|---|---|
| | Weight 2 Tempe (gr) | Weight 1 Tempe (gr) |
| 07.00 - 08.00 | 170 - 170 | 85 |
| 09.00 - 10.00 | 170 - 170 | 85 |
| 11.00 - 12.00 | 170 - 170 | 85 |
| 13.00 - 14.00 | 168 - 168 | 85 |
| 15.00 - 16.00 | 168 - 168 | 85 |
| 17.00 - 18.00 | 167 - 167 | 84 |
| 19.00 - 20.00 | 167 - 167 | 84 |
| 21.00 - 22.00 | 166 - 165 | 84 |
| 23.00 - 00.00 | 163 - 163 | 84 |
| 03.00 - 04.00 | 160 - 160 | 83 |
| 05.00 | 159 | 83 |

In Table 6 there is a process of reducing the weight of tempeh by fermentation using tools and manually. In fermentation using tools, 2 tempeh were used with a total weight at the beginning of 170 gr and a total weight at the end of 159 gr and in manual fermentation, 1 tempeh was used with a total weight at the beginning of 85 gr and a total weight at the end of 83. Based on the comparison that has been presented, it can be concluded that fermentation using tools can be faster than manual fermentation.

The 1st research data on the Design and Construction of Tempe Fermentation Equipment Using the Fuzzy Method to Determine the Level of Tempe Maturity includes a discussion of the 1st research which started from 07.00 am to 05.00 am the next day. The fermentation results in the 1st research can be seen in Figure 23 as follows.

Figure 23. Results of the 1th Research Fermentation

In Figure 23, the fermentation results carried out for 22 hours were successful with the results of tempeh that was cooked with the criteria of the fungus growing evenly, not smelly or rotten. In the data from the DHT11 sensor output in the 1st study which started from 07.00 am to 05.00 am the next day. Based on the data listed, the initial fermentation temperature was 29.5 ° C and humidity 82% with the tempeh still raw and the final fermentation temperature was 31.7 ° C and humidity 75% with the tempeh cooked. In the data from the loadcell sensor output in the 1st study which started from 07.00 am to 05.00 am the next day. Based on the data listed, the initial weight was 170 grams for 2 tempeh with the tempeh still raw and the final weight was 159 grams with the tempeh cooked. In the 1st study which started from 07.00 am to 05.00 am the next day. Based on the overall data listed, at 07.00 the temperature at the beginning of fermentation was 29.5°C and humidity 82% with the condition of raw tempeh which has the criteria of fungus not growing with a weight of 170 gr, at 19.00 the temperature was 32.8°C and humidity 69% with the condition of raw tempeh which has the criteria of fungus growing but not evenly with a weight of 167 gr, and at 05.00 the temperature at the end of fermentation was 31.7°C and humidity 75% with the condition of cooked tempeh which has the criteria of fungus growing evenly with a weight of 159 gr. Thus it can be concluded that fermentation was successful for 22 hours with a decrease in tempeh weight of 11 gr with the condition of cooked tempeh which has the criteria of fungus growing evenly, not smelly or not rotten.

The data of the 2nd research on the Design and Construction of Tempe Fermentation Equipment Using the Fuzzy Method to Determine the Level of Tempe Maturity includes a discussion of the 2nd research which started from 07.00 am to 00.00 am the next day. The results of fermentation in the 2nd research can be seen in Figure 25 as follows.

Figure 24. Results of the 2th Research Fermentation

In Figure 2, the fermentation results carried out for 17 hours were successful with the results of tempeh that was cooked with the criteria of the fungus growing evenly, not smelly or rotten. Thus, there is data from the output of the DHT11 sensor and the loadcell sensor in the 2nd study. There is data from the output of the DHT11 sensor in the 2nd study which started from 07.00 am to 00.00 am the next day. Based on the data listed, the initial fermentation temperature was 30.5 ° C and humidity 67% with the condition that the tempeh was still raw and the final fermentation temperature was 33.9 ° C and humidity 54% with the condition that the tempeh was cooked. There is data in the form of a graph from the output of the loadcell sensor in the 2nd study which started from 07.00 am to 00.00 am the next day. Based on the data listed, the initial weight of 172 grams was obtained for 2 tempeh with the condition that the tempeh was still raw and the final weight of 162 grams with the condition that the tempeh was cooked. The overall data in the 2nd study started from 07.00 am to 00.00 am the next day. Based on the overall data listed, at 07.00 the temperature at the beginning of fermentation was 30.5°C and humidity 67% with the condition of the tempeh still raw which has the criteria of the fungus not growing with a weight of 172 grams, at 15.00 the temperature was 33.4°C and humidity 58% with the condition of the tempeh still raw which has the criteria of the fungus has grown but not evenly with a weight of 169 grams, and at 00.00 the temperature at the end of fermentation was 33.9°C and humidity 54% with the condition of the tempeh already cooked which has the criteria of the fungus growing evenly with a weight of 162 grams. Thus it can be concluded that the fermentation was successful for 17 hours with a decrease in the weight of the tempeh of 10 grams with the condition of the tempeh already cooked which has the criteria of the fungus growing evenly, not smelly or not rotten.

The 3rd research data on the Design and Construction of Tempe Fermentation Equipment Using the Fuzzy Method to Determine the Level of Tempe Maturity includes a discussion of the 3rd research which started from 07.00 am to 04.00 am the next day. The fermentation results in the 3rd research can be seen in Figure 26 as follows.

Figure 25. Results of the 3th Research Fermentation

In Figure 25, the fermentation results carried out for 21 hours were successful with the results of tempeh that was cooked with the criteria of the fungus growing evenly, not smelly or rotten. There is data from the DHT11 sensor output in the 3rd study which started from 07.00 am to 04.00 am the next day. Based on the data listed, the initial fermentation temperature was 29.8 ° C and humidity was 82% with the tempeh still raw and the final fermentation temperature was 34.4 ° C and humidity was 64% with the tempeh cooked. There is data in the form of a graph from the loadcell sensor output in the 3rd study which started from 07.00 am to 04.00 am the next day. Based on the data listed, the initial weight was 171 grams for 2 tempeh with the tempeh still raw and the final weight was 160 grams with the tempeh cooked. Overall data in the 3rd study which started from 07.00 am to 04.00 am the next day. Based on the overall data listed, at 07.00 the temperature at the beginning of fermentation was 29.8°C and humidity 82% with the condition of raw tempeh which has the criteria of fungus not growing with a weight of 171 gr, at 20.00 the temperature was 33.8°C and humidity 69% with the condition of raw tempeh which has the criteria of fungus growing but not evenly with a weight of 165 gr, and at 04.00 the temperature at the end of fermentation was 34.4°C and humidity 64% with the condition of cooked tempeh which has the criteria of fungus growing evenly with a weight of 160 gr. Thus it can be concluded that fermentation was successful for 21 hours with a decrease in tempeh weight of 11 gr with the condition of cooked tempeh which has the criteria of fungus growing evenly, not smelly or not rotten.

The 4th research data on the Design and Construction of Tempe Fermentation Equipment Using the Fuzzy Method to Determine the Level of Tempe Maturity includes a discussion of the 4th research which started from 07.00 am to 02.00 am the next day. The fermentation results in the 4th research can be seen in Figure 27 as follows.

Figure 26. Results of the 4th Research Fermentation

In Figure 26, the fermentation results carried out for 19 hours were successful with the results of tempeh that was cooked with the criteria of the fungus growing evenly, not smelly or rotten. There is data from the DHT11 sensor output in the 4th study which started from 07.00 am to 02.00 am the next day. Based on the data listed, the initial fermentation temperature was 31.8 ° C and humidity was 71% with the tempeh still raw and the final fermentation temperature was 29.8 ° C and humidity was 82% with the tempeh cooked. There is data from the loadcell sensor output in the 4th study which started from 07.00 am to 02.00 am the next day. Based on the data listed, the initial weight was 170 grams for 2 tempeh with the tempeh still raw and the final weight was 158 grams with the tempeh cooked. Overall data in the 4th study which started from 07.00 am to 02.00 am the next day. Based on the overall data listed, at 07.00 the temperature at the beginning of fermentation was 31.8°C and humidity 71% with the condition of raw tempeh which has the criteria of fungus not growing with a weight of 170 gr, at 18.00 the temperature was 32.5°C and humidity 79% with the condition of raw tempeh which has the criteria of fungus growing but not evenly with a weight of 167 gr, and at 02.00 the temperature at the end of fermentation was 29.8°C and humidity 82% with the condition of cooked tempeh which has the criteria of fungus growing evenly with a weight of 158 gr. Thus it can be concluded that fermentation was successfully carried out for 19 hours with a decrease in tempeh weight of 12 gr with the condition of cooked tempeh which has the criteria of fungus growing evenly, not smelly or not rotten.

The 5th research data on the Design and Construction of Tempe Fermentation Equipment Using the Fuzzy Method to Determine the Level of Tempe Maturity includes a discussion of the 5th research which started from 07.00 am to 07.00 am the next day. The fermentation results in the 5th research can be seen in Figure 28 as follows.

Figure 27. Results of the 5th Research Fermentation

In Figure 27, the fermentation results carried out for 24 hours were successful with the results of tempeh that was cooked with the criteria of the fungus growing evenly, not smelly or rotten. There is data in the form of a graph from the DHT11 sensor output in the 5th study which started from 07.00 am to 07.00 am the next day. Based on the data listed, the initial fermentation temperature was 31.9 ° C and humidity was 81% with the tempeh still raw and the final fermentation temperature was 31 ° C and humidity was 86% with the tempeh cooked. There is data from the loadcell sensor output in the 5th study which started from 07.00 am to 07.00 am the next day. Based on the data listed, the initial weight was 170 grams for 2 tempeh with the tempeh still raw and the final weight was 159 grams with the tempeh cooked. There is overall data in the 5th study which started from 07.00 am to 07.00 am the next day. Based on the overall data listed, at 07.00 the temperature at the beginning of fermentation was 31.9°C and humidity 81% with the condition of raw tempeh which has the criteria of fungus not growing with a weight of 170 gr, at 19.00 the temperature was 33°C and humidity 77% with the condition of raw tempeh which has the criteria of fungus growing but not evenly with a weight of 166 gr, and at 07.00 the temperature at the end of fermentation was 31°C and humidity 86% with the condition of cooked tempeh which has the criteria of fungus growing evenly with a weight of 159 gr. Thus it can be concluded that fermentation was successful for 24 hours with a decrease in tempeh weight of 11 gr with the condition of cooked tempeh which has the criteria of fungus growing evenly, not smelly or not rotten.

The 6th research data on the Design and Construction of Tempe Fermentation Equipment Using the Fuzzy Method to Determine the Level of Tempe Maturity includes a discussion of the 6th research which started from 07.00 am to 09.00 am the next day. The fermentation results in the 6th research can be seen in Figure 29 as follows.

Figure 28. Results of the 6th Research Fermentation

In Figure 28, the fermentation results carried out for 26 hours were successful with the results of tempeh that was cooked with the criteria of the fungus growing evenly, not smelly or rotten. There is data from the DHT11 sensor output in the 6th study which started from 07.00 am to 09.00 am the next day. Based on the data listed, the initial fermentation temperature was 29.2 ° C and humidity was 87% with the tempeh still raw and the final fermentation temperature was 30.4 ° C and humidity was 82% with the tempeh cooked. There is data from the loadcell sensor output in the 6th study which started from 07.00 am to 09.00 am the next day. Based on the data listed, the initial weight was 169 grams for 2 tempeh with the tempeh still raw and the final weight was 160 grams with the tempeh cooked. There is overall data in the 6th study which started from 07.00 am to 09.00 am the next day. Based on the overall data listed, at 07.00 the temperature at the beginning of fermentation was 29.2°C and humidity 87% with the condition of raw tempeh which has the criteria of fungus not growing with a weight of 169 gr, at 21.00 the temperature was 33.5°C and humidity 75% with the condition of raw tempeh which has the criteria of fungus growing but not evenly with a weight of 165 gr, and at 09.00 the temperature at the end of fermentation was 30.4°C and humidity 80% with the condition of cooked tempeh which has the criteria of fungus growing evenly with a weight of 160 gr. Thus it can be concluded that fermentation was successful for 26 hours with a decrease in tempeh weight of 9 gr with the condition of cooked tempeh which has the criteria of fungus growing evenly, not smelly or not rotten.

The 7th research data on the Design and Construction of Tempe Fermentation Equipment Using the Fuzzy Method to Determine the Level of Tempe Maturity includes a discussion of the 7th research which started from 07.00 am to 06.00 am the next day. The fermentation results in the 7th research can be seen in Figure 29 as follows.

Figure 29. Results of the 7th Research Fermentation

In Figure 29, the fermentation results carried out for 23 hours were successful with the results of tempeh that was cooked with the criteria of the fungus growing evenly, not smelly or rotten. There is data in the form of a graph from the DHT11 sensor output in the 7th study which started from 07.00 am to 06.00 am the next day. Based on the data listed, the initial fermentation temperature was 29.5 ° C and humidity was 90% with the tempeh still raw and the final fermentation temperature was 33.6 ° C and humidity was 65% with the tempeh already cooked. There is data in the form of a graph from the loadcell sensor output in the 7th study which started from 07.00 am to 06.00 am the next day. Based on the data listed, the initial weight was 170 grams for 2 tempeh with the tempeh still raw and the final weight was 160 grams with the tempeh already cooked. There is overall data on the 7th study which started from 07.00 am to 06.00 am the next day. Based on the overall data listed, at 07.00 the temperature at the beginning of fermentation was 29.5°C and humidity 90% with the condition of raw tempeh which has the criteria of fungus not growing with a weight of 170 gr, at 20.00 the temperature was 34.1°C and humidity 65% with the condition of raw tempeh which has the criteria of fungus growing but not evenly with a weight of 165 gr, and at 06.00 the temperature at the end of fermentation was 33.6°C and humidity 65% with the condition of cooked tempeh which has the criteria of fungus growing evenly with a weight of 160 gr. Thus it can be concluded that fermentation was successful for 23 hours with a decrease in tempeh weight of 10 gr with the condition of cooked tempeh which has the criteria of fungus growing evenly, not smelly or not rotten.

There are overall data on the 1st study to the 7th study. In the 1st study, fermentation started at 07.00 using 2 packs of tempeh weighing 170 grams with a temperature of 29.5 ° C and finished at 05.00 with a weight of 159 grams with a temperature of 31.7 ° C, thus fermentation was successfully carried out for 22 hours with a decrease in tempeh weight of 11 grams with the criteria of evenly growing fungi. In the 2nd study, fermentation started at 07.00 using 2 packs of tempeh weighing 172 grams with a temperature of 30.5 ° C and finished at 00.00 with a weight of 162 grams with a temperature of 33.9 ° C, thus fermentation was successfully carried out for 17 hours with a decrease in tempeh weight of 10 grams with the criteria of evenly growing fungi. In the 3rd study, fermentation started at 07.00 using 2 packs of tempeh weighing 171 grams with a temperature of 29.8°C and finished at 04.00 with a weight of 160 grams with a temperature of 34.4°C, thus fermentation was successfully carried out for 21 hours with a decrease in tempeh weight of 11 grams with the criteria of evenly growing fungi. In the 4th study, fermentation started at 07.00 using 2 packs of tempeh weighing 170 grams with a temperature of 31.8°C and finished at 02.00 with a weight of 158 grams with a temperature of 29.8°C, thus fermentation was successfully carried out for 19 hours with a decrease in tempeh weight of 12 grams with the criteria of evenly growing fungi. In the 5th study, fermentation started at 07.00 using 2 packs of tempeh weighing 170 grams with a temperature of 31.9°C and finished at 07.00 with a weight of 159 grams with a temperature of 31°C, thus fermentation was successfully carried out for 24 hours with a decrease in tempeh weight of 11 grams with the criteria of evenly growing fungi. In the 6th study, fermentation started at 07.00 using 2 packs of tempeh weighing 169 grams with a temperature of 29.2°C and finished at 09.00 with a weight of 160 grams with a temperature of 30.4°C, thus fermentation was successfully carried out for 26 hours with a decrease in tempeh weight of 9 grams with the criteria of evenly growing fungi. In the 7th study, fermentation started at 07.00 using 2 packs of tempeh weighing 170 grams with a temperature of 29.5°C and finished at 06.00 weighing 160 grams with a temperature of 33.6°C, so fermentation was successfully carried out for 23 hours with a decrease in tempeh weight of 10 grams with the criteria of evenly growing fungi. Based on the overall data that has been presented above, the fastest fermentation was in the 2nd study and the longest fermentation was in the 6th study, it can be concluded that the good temperature for tempeh fermentation is 30.5 - 33.9°C and it is attempted to keep the temperature stable.

Based on research conducted in 2022 [43]. There is a gap in this research. Previous research has shown that this tool is effective in maintaining the temperature of the fermentation room in the range of 30°C to 37°C, with the fastest fermentation time at 35°C for 22 hours. This microcontroller-based tool functions to accelerate the fermentation process compared to manual methods, but only focuses on controlling temperature and humidity. In contrast, this research is more innovative by integrating DHT11 sensors, loadcells, and ESP32CAM using the Mamdani fuzzy method. This tool not only regulates temperature and humidity, but also determines the level of tempeh maturity accurately through weight and visual analysis. With a fermentation time of 17-24 hours and success criteria in the form of evenly growing mushrooms without a bad odor, this study shows a more precise multi-parameter approach than simple control in microcontroller research [43], [44].

Mamdani fuzzy-based research has more comprehensive success indicators, including tempeh quality, weight loss, and visual monitoring during fermentation, so that the results are more detailed and accurate. While microcontroller-based research has only had a limited impact on fermentation time efficiency, Mamdani's fuzzy research supports the modernization of the tempeh industry by including increasing productivity, efficiency, and competitiveness[45]. The intelligent approach based on fuzzy logic makes this research more relevant for industrial scale applications, offering technological innovation in managing tempeh fermentation that is more measurable and of high quality[40]- [42].

This research offers novelty with a multi-parameter approach that integrates temperature and humidity (DHT11 sensor), weight (loadcell sensor), and visual analysis (ESP32CAM) to determine the level of tempeh maturity more accurately. By applying the Mamdani fuzzy method, this tool adaptively manages automatic devices such as incandescent lamps and fans based on sensor data, ensuring optimal fermentation conditions and flexibility to environmental changes. In addition, the integration of loadcell technology to measure tempeh weight loss and ESP32CAM to visually monitor mold growth provides innovative quantitative and qualitative analysis, surpassing previous research that only focused on temperature control[43]-[45]. This tool is also able to accelerate the fermentation process to 17-24 hours with high-quality tempeh results, characterized by evenly growing mold without a bad odor, making it more efficient than conventional methods or microcontroller-based research. Furthermore, this tool is designed to support the modernization of the tempeh industry with artificial intelligence-based technology, increasing production efficiency, maintaining quality consistency, and making it more competitive in local and global markets. This innovation contributes significantly to the development of adaptive, modern, and relevant tempeh fermentation technology to the needs of the technology-based food industry.

This study has several limitations that need to be considered. The tool designed is still in the form of a laboratory-scale prototype, so it has not been optimally tested for large-scale production in the tempeh industry. In addition, this tool is highly dependent on the performance of hardware such as sensors and software based on fuzzy algorithms. Damage to components or algorithm failure can significantly affect the performance of the tool, so the reliability of the tool needs to be improved. This study also has not explored the performance of the tool in different environments, such as areas with extreme temperatures or humidity, which can affect fermentation results. Finally, the complexity of using the tool is a challenge in itself, because it requires a certain technical understanding for optimal operation. This can be an obstacle for traditional tempeh industry players, who may need training to be able to use the tool properly [46]-[48].

For further development, this research is recommended to be tested on an industrial scale to assess its performance in mass production and ensure that the device can work well under complex operational conditions. Improvements to the design are needed to increase the durability of the components and the stability of the fuzzy algorithm so that the device can be used in the long term without technical disruptions. In addition, testing in various environmental conditions, such as areas with high humidity or low temperatures, is recommended to increase the flexibility of the device[49]-[51]. A user-friendly interface, such as a smartphone-based application, also needs to be developed to make it easier for traditional tempeh industry players to monitor and control the device. Furthermore, this technology can be expanded to other fermented products, such as tofu, yogurt, or tape, thus expanding its benefits in the fermented food industry . With these steps, the designed device is expected to be widely adopted and provide maximum impact in the modernization of the tempeh industry and other fermented products.

## 4. CONCLUSION

This study successfully designed and operated a tempeh fermentation tool based on the Mamdani fuzzy method with satisfactory results without any problems. This tool was tested 7 times with the fastest fermentation time of 17 hours at a temperature of 30.5–33.9°C, the longest time of 26 hours at a temperature of 29.2–30.4°C, and an average of 21.7 hours, producing tempeh with even mold growth and no bad odor. The load cell sensor is able to weigh the tempeh and provide a buzzer output when the tempeh is cooked, with an average weight loss of 10.5 grams, while the ESP32CAM successfully monitors the visual condition of the tempeh during fermentation. The temperature control system using the DHT11 sensor with the Mamdani fuzzy method works optimally through three automatic conditions that adjust the fan and lights to maintain the ideal temperature. This tool not only speeds up the fermentation process compared to the manual method (18-48 hours) but also ensures better product quality, supports the modernization of the tempeh industry based on artificial intelligence, and opens up opportunities for the development of similar technology for other fermentation products in the field of traditional food technology.

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