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Design and Performance Test of Brown Rice Germinator with Automatic Environmental Control System for Production of Germinated Brown Rice

Ressy Angli Permatasari[1,✉], Sutrisno[1], I Wayan Budiastra[1], Haris Mawardi[1], Angga Firmansyah[1], Arfandi Hermawan[2], Elisa Eka Ari Purwanti Ningsih[2]

[1] Department of Mechanical and Biosystem Engineering, Faculty of Agricultural Engineering and Technology, IPB University, Bogor, INDONESIA.

[2] Department of Mechanical and Biosystem Engineering, Faculty of Agricultural Engineering and Technology, Brawijaya University, Malang, INDONESIA

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Corresponding Author:
✉ ressyangli@apps.ipb.ac.id
(Ressy Angli Permatasari)

ABSTRACT

A germinator equipped with automatic environmental control system has been developed to produce the high quality of germinated brown rice. The germinator consists of germination chamber, temperature and relative humidity sensors, relays, actuator, and display panel so the germination process can be set up and controlled. The performance test were carried out covering the technical reliability of the system and the capability of germinator to produce germinated brown rice. The test results show that the brown rice germinator *with an automatic environmental control system worked very well. The use of water misters and PTC air heaters is able to maintain humidity and air temperature inside germinator. The* brown rice germinator *can produce germinated brown rice with germination rate more than 80%. The result shows that the* brown rice germinator *can be used to produce germinated brown rice both for private and commercial use.*

1. INTRODUCTION

Brown rice is increasingly popular for consumption due to its higher nutritional value compared to regular white rice (Charoenthaikij *et al*., 2009). Brown rice is rice from which only the husk is removed but not polished into white rice. Brown rice contains more protein, lipids, vitamins, minerals, fiber, and antioxidants than white rice (Munarko *et al*., 2019). Brown rice consumption shows valuable health benefits for many diseases, such as coronary heart disease, hypertension, diabetes, metabolic syndrome, and colon cancer (Ying *et al*., 2022). Brown rice consists of bran, embryo, and endosperm layers (Chungcharoen *et al*., 2015). The acceptability of brown rice is still low because it has a coarse texture compared to white rice. The level of water absorption by brown rice is lower, so the cooking process is more difficult and takes longer (Wu *et al*., 2013). The acceptability of brown rice as a consumable can be improved through various bioprocesses, including germination (Cáceres *et al*., 2014). Brown rice germination can change the physical shape of the rice grain due to the growth and elongation of the shoots (Banchuen, 2010). Optimum germination conditions are desired, indicated by the emergence of shoots with a size of 0.5–5 millimeters (Patil & Khan, 2011). Brown rice with a germination process aims to increase the content of nutritional value and bioactive components (Cho & Lim, 2016); besides that, germinated brown rice has a softer texture and is easier to cook (Munarko *et al*., 2019). The preparation of germinated brown rice can generally be done by two methods: the first is by full soaking, and the second method is a combination of soaking and incubation in an atmospheric environment. According to Munarko *et al*. (2019), germination methods can be carried out by full soaking and germination with a combination of soaking and incubation.

Partial germination techniques with a combination of soaking and germination under atmospheric conditions produce a higher degree of germination compared to full soaking so that the rice has longer shoots (Cho & Lim, 2016). In addition, optimization of germination conditions in brown rice is important to optimize physical and organoleptic properties. In their research, Lu *et al*. (2010) added that the atmospheric germination process resulted in a higher germination rate than simple water immersion, where germinated brown rice (GBR) produced longer shoots. According to Patil & Khan (2012), it is also mentioned that germinated brown rice is able to shorten the cooking time compared to regular brown rice that does not go through the germination process.

Germinator for germinated brown rice is a tool that can control environmental conditions for germination of germinated rice. A germinator is a device with temperature and humidity settings commonly used to germinate rice with the aim of maintaining optimum germination conditions (Ichsan, 2006).

Conventional production of germinated brown rice using the full-soaking method is the simplest method. However, this method requires a long time, making it less suitable for commercial production purposes. Therefore, it is necessary to design a brown rice germinator tool with an automatic environmental control system. The purpose of the research is to design a Brown rice germinator with an Automatic Environmental Control System and conduct Performance Tests for the Production of Brown Rice Germinated.

2. MATERIALS AND RESEARCH METHODS

2.1. Tools and Materials

Materials used for germinator design include acrylic, aluminum foil, pvc pipe, catch basin, and electronic components such as ptc air heater, mist maker fan (8 cm, 6 cm), Arduino Uno, DHT21 sensor, relay, 16x2 LCD, and LCM1602 IIC1 LCD. Materials used for germinator testing include: Inpari-32 brown rice, water, cup, aluminum, cotton, plastic tray, and plastic wrap.

2.2. Tool Design

2.2.1. Structural Design

The structural design of the brown rice germinator tool designed in this study can be seen in Figure 1. The germinator box has a size of 30 cm x 30 cm x 40 cm and is made of acrylic material coated with aluminum foil on the inside, as shown in Figure 1. The thickness of the acrylic used is 4 mm. The door is located at the front of the germinator box to facilitate the input of samples or experimental materials, while the hole in the center of the back is used for pipes with a diameter of 5 cm and a length of 15 cm. Inside the germinator box, there are 3 shelves measuring 26 cm x 36 cm. The

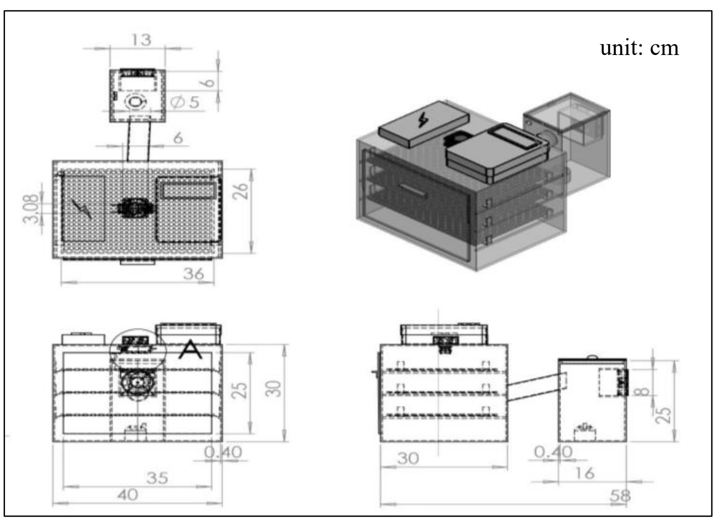


Figure 1. Structural design of brown rice germinator

shelves are made to have holes to facilitate air circulation. The top of the germinator box is equipped with a PTC air heater, fan, and control box, with the location of the control box in the upper left corner. The control box is made of plastic with a size of 20 cm x 15 cm x 10 cm, containing instrumentation equipment that functions to regulate temperature and humidity and is equipped with an LCD display. Inside the germinator box there is a DHT21 sensor to measure temperature and humidity. Behind the germinator box is a water reservoir measuring 13 cm x 16 cm x 25 cm and made of acrylic with a thickness of 4 mm. The tub contains a set of water misters, namely a mist maker and a fan measuring 8 cm x 8 cm. The resulting water vapor will be blown through the pipe to the germinator box.

2.2.2. Functional Design

Germination of hulled rice is an important process in producing healthy and high-quality rice. To help speed up and optimize the process of hulled rice germination, a tool called a brown rice germinator is used. This tool has several functions that are very important in ensuring that the germination process goes well, including regulating the temperature and humidity of the air in the germinator box, providing water mist in the germinator box, providing a suitable place and environment for brown rice germination, and displaying information on environmental conditions and brown rice germination results. The functions of the parts in the brown rice germinator are as follows:

a) The germinator box serves as a place where germination takes place. It is in this germinator box that environmental conditions will be controlled to accelerate the germination process of brown rice. The germinator box must be lightproof because the germination process is a dark reaction or without the help of sunlight.

b) Trays or shelves are used to place trays containing brown rice to be germinated. The main purpose of adding a tray is to increase the capacity of the germinator so that the energy that has been expended can be maximally utilized. The tray should have small holes to even out the air flow.

c) Trays and seed paper are used for the brown rice to germinate. This tray will be placed on the trays in the germinator.

d) The fan serves to maintain air circulation in the germinator so that the temperature and humidity that have been controlled can be leveled throughout the germinator.

e) The mist maker serves to atomize the water in the water reservoir so that further water vapor is channeled into the germinator so that the humidity of the germinator can be maintained.

f) The water reservoir serves to hold water that will be atomized by the mistmaker.

g) The pipe functions as a distributor of water vapor from the reservoir to the germinator.

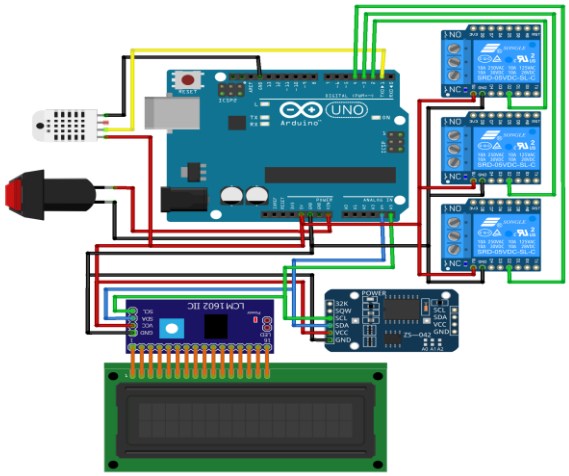
h) The PTC Air Heater serves as an air temperature controller in the germinator room.

2.2.3. Electronics Design

The brown rice germinator system is a system used to control and monitor the brown rice germination process. This system operates using several electronic components, including Arduino UNO as the control center. The electronic components used in the design of the brown rice germinator tool are shown in Figure 2.

DHT21 sensor to measure the temperature and humidity values in the germinator. Relay is used as an actuator for on/off fan components, mist maker, and PTC air heater. 16x2 LCD as a screen to display system information, and LCM1602 IIC1 LCD as a link between the LCD screen and Arduino UNO.

Arduino UNO gets air temperature and humidity data from the DHT21 sensor, then the information is used to control the actuator through the relay to maintain the desired air temperature and humidity in the system. The 16x2 LCD screen displays the information of temperature, humidity, time, and other system settings, which can help the operator in monitoring the system condition. The LCM1602 IIC1 LCD serves as the link between the LCD screen and the Arduino UNO and allows data to be displayed on the screen accurately and easily read. Overall, the electronic components used in the brown rice germinator system are important in maintaining the right temperature, humidity, and timing for optimal and high-quality germination of brown rice.



Main components of electronic:

1. Arduino UNO
2. DHT21 sensor
3. Relay 4 channel
4. 16x2 LCD
5. LCM1602 IIC1 LCD
6. RTC DS3231
7. Push button

Figure 2. Electronics circuit

2.3. Performance Test Procedure

2.3.1. Soaking

Rice germination occurs when the rice is in a state of dormancy or rest. One way to trigger shoot growth in dormant rice is through the imbibition process, which is by giving water to the rice so that water can stimulate shoot growth. Before the germination process is carried out on brown rice of the Inpari-32 variety using a germinator, pretreatment or soaking of the rice is carried out. The soaking stages include the preparation of the necessary tools and materials, washing the brown rice until clean, and soaking the sample in water for 4 hours for the rice imbibition process.

2.3.2. Germination

The germination process is carried out on brown rice that has gone through the soaking process using a designed germinator. In this study, the treatment factor used was germination time with treatment levels (12, 14, 16, 18, and 20 hours) and 3 replications. The controlled environment includes temperature and relative humidity (RH). The ideal temperature for brown rice germination is 27-30°C, and the ideal relative humidity (RH) is 87-90%.

The steps of the germination process can be done by: a) preparing tools and materials; b) connecting the germinator plug to the power source; c) Setting the temperature and the length of time of germination in the brown rice germinator; d) Wetting the cotton in each aluminum foil cup as a germination medium. e) Inserting 5 grams of samples that have gone through the soaking process in each cup that has contained cotton; f) Covering aluminum foil cups using plastic wrap to reduce the acceleration of the evaporation process and avoid contamination; g) Labeling aluminum foil cups so that the samples are not mixed up, h) Brown rice samples are put into the germinator; i) Germination process with the time that has been set on the germinator; j) Calculate the results of germination based on the parameters observed (germination power).

2.4. Performance Test Parameters

2.4.1. Hardware Testing

Before testing, the entire system circuit is checked first to make sure there is no circuit that is detached or not connected to the Arduino UNO. After the circuit is checked, testing is carried out on the hardware components consisting of:

a) DHT21 Sensor: To ensure the accuracy of air temperature and humidity measurements by the DHT21 sensor, a comparison is made with the Thermo Pro standard tool. After the comparison, the error value is calculated using the Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE) methods according to formulas (1) and (2) (Moreno *et al.*, 2013). RMSE measures the error rate of the model based on the sum of the squared error, or the difference between the actual value and the predicted value. MAPE measures the percentage error of the predicted result of the calibration equation compared to the actual value of the standard sensor.

$$\text{RMSE} = \sqrt{\sum \frac{(Y' - Y)^2}{n}} \quad (1)$$

$$\text{MAPE} = \frac{1}{n}\sum_{t=1}^{n} \frac{|Y - Y'|}{Y'} \times 100 \quad (2)$$

where *Y* is the actual value, *Y'* is the predicted value, and *n* is the number of data.

b) Relay: To test the performance of the relay, it is done by looking at the indicator light found on the relay and comparing it with the actuator. If the indicator light is on and the actuator is also on (ON), it can be said that the relay is functioning properly. Vice versa for testing the system in the off condition (OFF).

2.4.2. Germination Testing

Germination testing is conducted to determine the success of a brown rice germinator tool used in brown rice germination on the results obtained. The germination test parameter used is the percentage of normal germination based on the assessment of the embryo growth structure observed directly (Sari & Faisal, 2017). Based on SNI 01-6233-201, germination shows the ability of rice to grow into normal sprouts under optimum conditions expressed in percent (minimum 80%) (BSN, 2015). Then, the number of rice that successfully germinated and the number of rice that did not germinate were calculated using the formula done by Nurrachmamila & Saputro (2017).

$$DK = \frac{JK}{JC} \times 100\% \quad (3)$$

where *DK* is germination power, *JK* is number of normal sprouts produced, and *JC* is the number of rice tested.

3. RESULTS AND DISCUSSION

3.1. Results of Brown Rice Germinator Tool Design

3.1.1. Tool Description

Brown rice germinator with automatic environment control system is a tool designed to produce brown rice sprouts with high time efficiency and controlled environment. This tool is capable of handling up to 1.2 kg of brown rice in one germination process. With a large enough capacity, it allows users to process a larger amount of rice in a single operation, which can improve process efficiency.

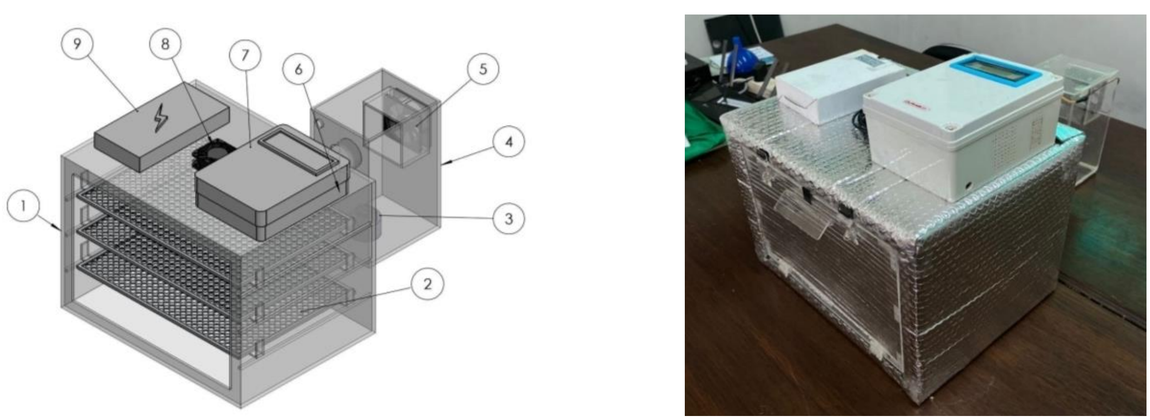
The germination box is one of the main components in this tool. With dimensions of 30 cm x 30 cm x 40 cm and an empty weight of 3 kg, the germination box is designed with a symmetrical size that makes it easy to use and move the tool. Inside the germination box, there are 3 trays of shelves and 1 base, which can accommodate an appropriate amount of brown rice seeds. Each brown rice tray is equipped with seed paper measuring 30 cm x 22 cm as a medium for sprout growth. This seed paper or cotton ensures an optimal environment for rice germination so that the sprouts can develop properly. The capacity of each tray ranges from 200 to 300 grams, so the total capacity of the device consisting of 3 to 4 trays reaches 800 to 1200 g.

In addition, it is equipped with an environmental control system that includes temperature and relative humidity (RH) controllers. The ideal temperature for brown rice germination is 27–30°C, while the ideal relative humidity is 87-90%. This environmental controller aims to create optimal conditions for the germination process. The controlled temperature and humidity will be regulated to be evenly distributed throughout the germination room with the help of fans. Regular and even air circulation will ensure consistent temperature and humidity throughout the germination area, allowing the rice to grow properly. In addition, the device is also equipped with a mist maker located in the water trough behind the germination box. The mist maker aims to humidify the air inside the germination box, creating environmental conditions that are suitable for the growth needs of the sprouts.

3.1.2. Structural and Functional Design Results

In this research, the structural and functional design results can be seen in Figure 3. Important component of this germinator is described briefly as the following.

1) Box germinator: has a size of 30 cm x 30 cm x 40 cm and is made of acrylic material coated with aluminum foil on the inside. Acrylic material with a thickness of 4 mm provides sufficient structural strength to withstand the load and maintain the required temperature. Aluminum foil on the inside serves to keep the room dark, reflects heat, and maintains the desired temperature in the box. Inside the germinator box is equipped with a DHT-21 sensor placed at the bottom of the germinator box to represent the overall environmental conditions of the box.
2) Shelves: there are 3 shelves measuring 26 cm x 36 cm in the germinator box with 1 germinator base so that there are a total of 4 shelves in the germinator. These shelves are used to place samples or experimental materials. The shelves are designed with holes to facilitate air circulation inside the germinator box. This design ensures that the air contained in the germinator box can flow properly around the shelves.
3) 4) 5) Mist maker, water tank, and fan: behind the germinator box is a water tank measuring 13 cm x 16 cm x 25 cm made of acrylic. The tub is equipped with a mist maker and a fan measuring 8 cm x 8 cm. The mist maker serves to produce water vapor, which will later be blown into the germinator box. The 8 cm x 8 cm fan helps push the water vapor into the germinator box through the pipe. This combination of mist maker and fan ensures sufficient moisture inside the germinator box for the rice planting process.
6) Pipes: A PVC pipe with a diameter of 5 cm and a length of 15 cm is located at the back center of the germinator box. This pipe is used to drain the water vapor generated from the water reservoir and mist maker into the germinator box. The design of the pipe integrated with the germinator box with a slope of about 20 degrees allows the flow of water vapor efficiently into the germinator box.
7) Control Box and LCD display: the control box is located in the upper left corner of the top of the germinator box. The control box is made of plastic with a size of 20 cm x 15 cm x 10 cm. This control box contains instrumentation equipment that serves to regulate the temperature and humidity in the germinator box. The LCD display on the control box displays the temperature and humidity measured from the DHT21 sensor in the germinator box.
8) Fan and PTC air heater: at the top of the germinator box there is a hole measuring 3 cm x 7 cm to place the PTC air heater in the germinator box. On top of the PTC air heater, a 6 cm x 6 cm fan is placed to supply air that is blown past the PTC air heater to produce hot air that circulates in the germinator box. This hot air serves as a temperature controller in the germinator box.
9) Power supply: measuring 10 cm x 20 cm x 3 cm placed above the germinator box adjacent to the control box to facilitate control and maintenance. This device functions as a power provider for electronic devices and converts AC current into DC to be distributed to devices with DC current.



(a) (b)

Figure 3. Brown rice germinator: (a) Design, (b) Real germinator. [(1) Box Germinator; 2) Shelves; 3) Mist maker; 4) Water tank; 5) Fan 8 cm x 8 cm; 6) Pipes; 7) Control Box dan LCD Display; 8) Fan 6 cm x 6 cm dan PTC Air Heater; 9) Power Supply]

3.2. Brown Rice Germinator Control System Design Results

3.2.1. Electrical System Design Results

The design of the environmental control system consists of three main components, namely input, process, and output (actuator). Input in the form of air temperature and humidity data obtained from the DHT21 sensor; data processing is carried out on the Arduino UNO microcontroller; then the output is in the form of actuator setting logic using a 4-channel relay. Relay functions to set ON or OFF on the actuator. Relay 1 regulates the heater, relay 2 regulates the heater fan, relay 3 regulates the mist maker, and relay 4 regulates the mist maker fan. After an adjustment from the initial plan, the DHT22 sensor is replaced with DHT21 and does not use RTC because it can use the 'mailing list' library found on the Arduino UNO. The circuit used is shown in Figure 5.

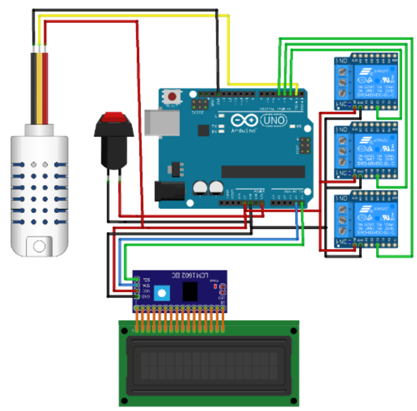


Figure 5. Electronic circuit

Table 1. Power requirements for each component

Component	Power Requirement (V)
Arduino UNO	5
Sensor DHT21	5
Relay	5
LCD	5
Heater	220
Mist maker	24
Fan	12
Buzzer	5

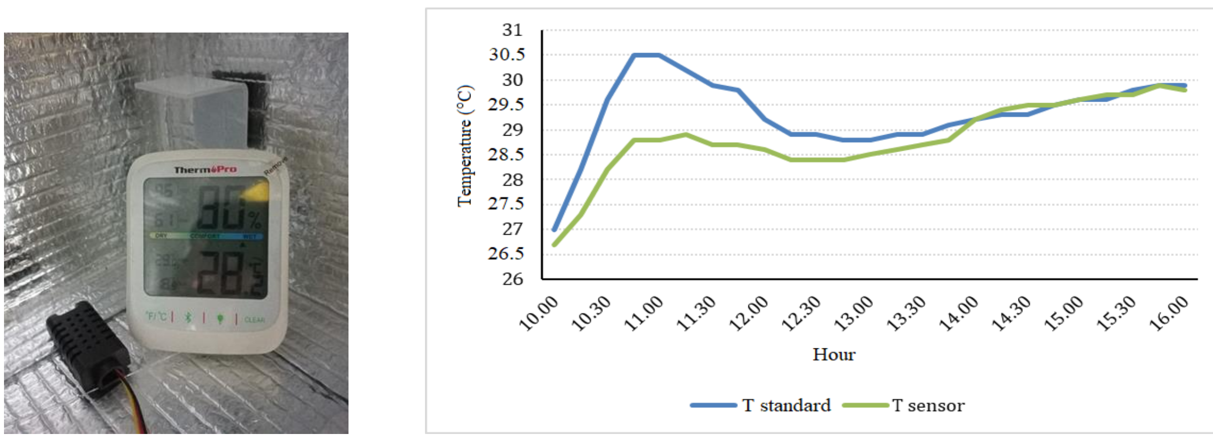
The power settings given need to be considered because each electronic component has different power requirements. The power requirements are listed in Table 1, which are regulated using a stepdown. The main power received of 220V is lowered according to the power requirements and then channeled to each component. The power supply, when connected to the power source, will continue on the stepdown, then be lowered and forwarded according to the power requirements of each component. The DHT21 sensor will read the real-time air temperature and humidity values and be sent to the Arduino UNO to be processed according to the program on the logic that has been uploaded. Relay logic uses an ON/OFF control system that is regulated by the 'if/else' program code on Arduino. Heater and heater fan will be ON when the air temperature is read <27°C and OFF when the optimum air temperature is reached, which is 30°C. Mist maker and mist maker fan will be ON when air RH <88% and OFF when air RH >90%. Heater and heater fan will also be ON when the air RH is >93% to lower the air RH because according to the literature it is mentioned that too high air RH is not good for the brown rice sprouting process. The temperature and humidity settings are adjusted to the optimum temperature and humidity literature for the germination process of Inpari32 brown rice. In addition to relay logic, Arduino UNO also stores information on the germinator startup time in the program code mailing list so that the buzzer will turn ON to provide a sound indicator that tells you that the germination process is complete.

3.2.2. Control System Testing

a) DHT21 Sensor Testing

The DHT21 sensor testing was conducted by comparing the temperature and humidity readings with a standard device, the Termo Pro, as shown in Figure 6a. The system testing process was carried out simultaneously with the relay testing according to the ON/OFF logic. This testing process was conducted for 6 hours under conditions using hulled rice material, similar to the germination testing process. The testing period is assumed to have provided information after one germination process, which is 12 hours. The test results are shown in Figure 6b for air temperature and then Figure 7 for air humidity inside the germinator box.

The calculation results show an RMSE value of 0.76 and a MAPE of 2% for the air temperature sensor, as well as an RMSE of 10.47 and a MAPE of 13% for the air humidity sensor. An RMSE value that approaches 0 indicates a smaller error value. A MAPE value <10% indicates very good accuracy (Lewis, 1982). Based on the calculations, it is known that the air temperature reading value is very good, while the air humidity reading value is quite good because the MAPE value is above 10% but not too far off, making it still acceptable.



(a) (b)

Figure 6. (a) DHT21 sensor testing, and (b) Air temperature graph inside the germinator box

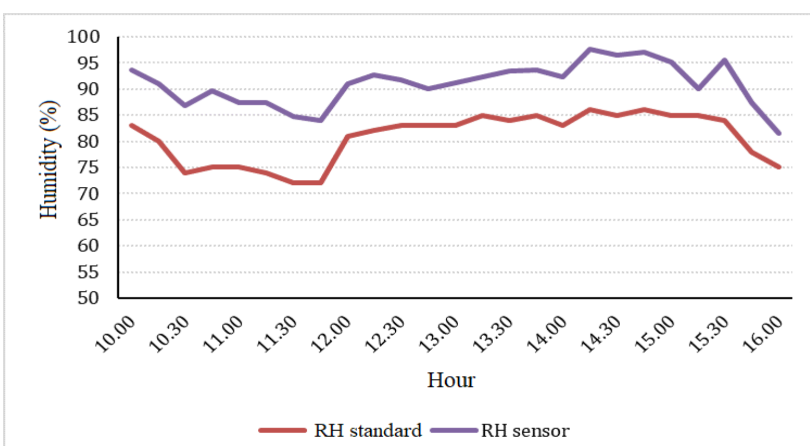


Figure 7. Air humidity graph inside the germinator box

b) Relay Testing

Relay logic testing is conducted simultaneously with DHT21 sensor testing. Overall, the relay logic works well. When the air temperature or humidity is not optimal, the actuator will turn on (ON) as needed, while when the air temperature or humidity reaches the optimal value, the actuator will turn off (OFF). Therefore, the relay logic testing was 100% successful according to the DHT21 sensor reading values, the Arduino UNO data processing, the relay logic settings, and the ON/OFF of the actuators, namely the heater, heater fan, mist maker, and mist maker fan.

3.2.3. Sprout Power (germination rate)

Sprout power is the most influential parameter in the design results of the tool. According to Suarni & Patong (2007), the germination power of rice can be defined as the blooming and development of the important parts of a rice embryo, which indicates its ability to grow normally in a suitable environment. The results of the sprouting power of hulled rice using a germinator and without a tool are shown in Figure 8. Observation of germination capacity aims to determine the development of important parts of a seed embryo, which indicates its ability to grow normally in a suitable environment. Rice is said to have sprouted when there are sprouts measuring at least 0.5-1 mm (Cho & Lim, 2016). In general, whether using tools or not, the germination process occurred within 12 hours. However, rice sprouts using tools tended to be longer compared to those without tools. This indicates that environmental conditions and differences in germination time significantly affect the speed of rice germination (Liu *et al*., 2013).

Observation of germination power was conducted after the hulled rice underwent the germination process using a germinator within a specified time limit. Germination power observation was carried out in 3 replications to determine the germination power results for each treatment, requiring data on the amount of material (amount of rice in 5 grams) and the amount of material that successfully germinated. After calculations using the germination power formula, the data shown in Figure 9 was obtained.

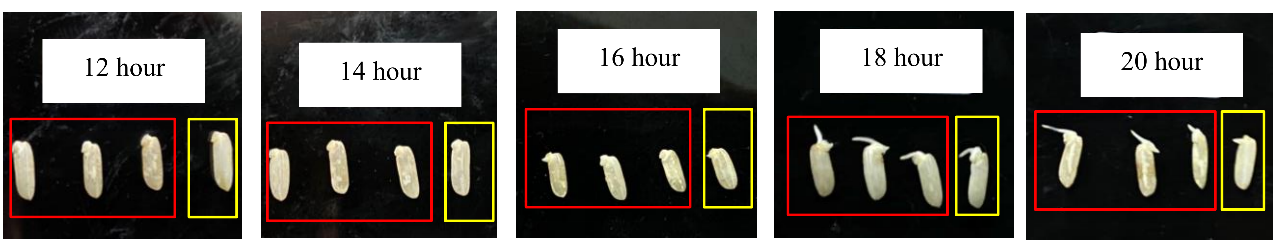


Figure 8. Sprouted rice using a germinator (red) and without a germinator (yellow) under various sprouting time treatments

Figure 9 shows the germination power values at different germination times using and without tools. Germination capacity is the percentage of seeds or rice that successfully germinate. At the 12-hour mark, when using the tool, the germination rate reached 86.84%, whereas without the tool it only reached 65.59%. This indicates that the use of the tool can significantly enhance the germination rate. When the time increased to 14 hours, a better improvement was observed in both methods. The germination rate with the tool reached 88.01%, while without the tool it reached 75.69%. This difference indicates that the use of the tool still provides an advantage in improving germination rate. At the 16-hour mark, there was a slight decrease in germination power with the tool to 86.88%, but it remained higher than without the tool, which reached 80.57%. Despite the decrease, the use of the tool still provided significant benefits. When the time reached 18 hours, there was a more significant decrease in both methods. The sprouting power with the tool reached 84.26%, while without the tool it reached 84.44%. At this point, the difference between using the tool and not using it is almost insignificant. However, at the 20-hour mark, the use of the tool once again provided a clear advantage. The germination rate with the tool reached 88.14%, while without the tool it reached 88.57%. Although the difference is small, the use of the tool still provides a slight advantage in improving the germination rate. Overall, based on the graph results, the germination of the hulled rice variety Inpari using the tool is quite good and meets the requirements. Where the minimum sprouting power requirement is 80% (Mulsanti *et al*., 2014). This is also mentioned by Prabandharu & Saputro (2017), that the sprouting power of rice has a minimum limit of 80%.

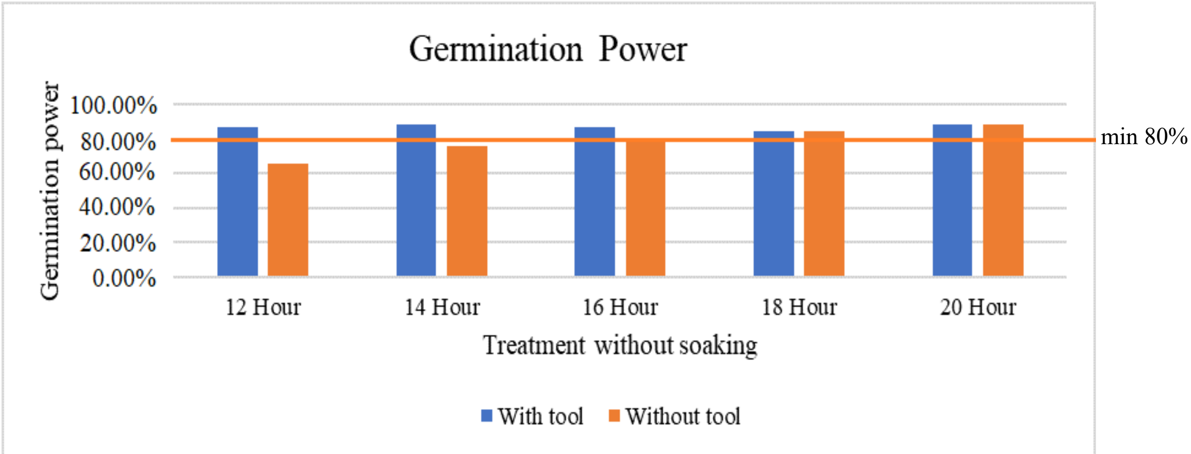


Figure 9. Graph of germination power values. (The minimum value is based on Mulsanti *et al*., 2014)

4. CONCLUSION

Based on the results of the brown rice germinator design with an automatic environmental control system, it shows that the tool can be used effectively in producing sprouted brown rice with high time efficiency and a controlled environment. In the testing, this tool successfully increased the sprouting power of hulled rice to over 80%. Additionally, the use of a water sprayer and PTC water heater was able to maintain humidity and air temperature inside the germinator. Sprouted brown rice produced from the brown rice germinator undergoes significant changes in terms of physical, chemical, and nutritional properties. The brown rice germinator has the potential to be used in the production of sprouted brown rice with high efficiency, both for personal and commercial use.

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