https://doi.org/10.17221/21/2023-RAE

# Fabrication and performance test of a multipurpose ohmic heating apparatus with a real-time data logging system based on low-cost sensors

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**Citation:** Sagita D., Hidayat D.D., Darmajana D.A., Rahayuningtyas A., Hariadi H. (2024): Fabrication and performance test of a multipurpose ohmic heating apparatus with a real-time data logging system based on low-cost sensors. Res. Agr. Eng., 70: 23–34.

**Abstract:** Ohmic heating is an emerging technology currently in high demand for application in various processes. In this research, a prototype of a multipurpose ohmic heating apparatus was successfully designed, fabricated, and tested. This apparatus was designed based on low-cost and versatile sensors and components available worldwide. Three independent chambers could be operated parallelly and individually with different treatments. Parameter data, i.e., voltage, electrical current, the temperature of heated material and environmental humidity-temperature, could be recorded by an embedded data logging system. The sensor had been tested and validated by comparing all the sensors used with commercial standard instruments. The result showed that all sensors had high measurement accuracy, indicated by very low mean absolute error (MAE) and mean absolute percentage error (MAPE), with $R^2 > 0.999$. The performance test revealed that product temperature could be accurately maintained according to the set point temperature with a deviation value lower than 0.1 °C. The data logging system was able to record and store the parameter data in SD card memory for up to several days without interruption. The prototype of the ohmic heating apparatus could be an effective alternative to process many purposes such as pasteurisation, cooking, warming, and fermentation based on the ohmic heating principle.

**Keywords:** Arduino-based equipment; electrothermal treatment; emerging technology; moderate electric field

Researchers increasingly develop innovative equipment for processing agricultural and food products based on emerging technologies. The concepts reflected in the definition of emerging technology have criteria including rapid recent growth, in the process of transition and/or change, market or economic potential that has not been fully exploited, and increasingly science-based (Cozzens et al. 2010). Emerging technologies have made significant strides in recent years, with pulse electric field (PEF), moderate electric field (MEF), ohmic heating, ultrasound, cold plasma, and other methods demonstrating potential for a wide range of applications (Chizoba Ekezie et al. 2017; Gavahian and Tiwari 2020; Bhargava et al. 2021; El Kantar and Koubaa 2022; Parniakov et al. 2022; Vorobiev and Lebovka

Supported by the National Research and Innovation Agency-Indonesia (Grant No. B-169/III/PR.03/5/2021).

https://doi.org/10.17221/21/2023-RAE

2022). Ohmic heating or Joule heating is one of the emerging technologies currently being explored and applied for many purposes. It has the function of heating products by transmitting electric current directly to the material (Sakr and Liu 2014). Heat is generated internally due to an electric current flowing in material via electrodes placed on both sides of materials/products (Marra et al. 2009). It is based on Ohm's Law, where the product acts as a load that resists the flow of electricity (Sagita et al. 2021). As a result of the electrical resistance, the temperature of the material increases as long as the voltage is applied. Research related to ohmic heating is increasingly in demand and is increasingly being applied, especially in the fields of food and agriculture. This is due to several advantages of ohmic heating, i.e. uniform heating (low-temperature gradient), instant on-off control without large temperature overshoots, and high energy efficiency (Sagita et al. 2022). It was reported that the temperature distribution of agricultural and food ingredients such as juice, potatoes, tubers and even wet coffee beans heated by ohmic heating showed a uniform temperature distribution (Faruk et al. 2017; Sabanci and Icier 2017; Gratz et al. 2021; Sagita et al. 2022). In addition, the energy efficiency of ohmic heating could reach more than 90% (Sagita et al. 2022).

Ohmic heating has several drawbacks due to depends on the type of electrode material, the type of material heated, and the electrical conductivity (EC) of the heated material (Sakr and Liu 2014). According to the literature, the electrode should be made of a non-corrosive material resistant to electrolysis reactions (Athmaselvi et al. 2017). The best material for electrodes was platinised titanium and graphite, followed by titanium nitride (TiN coated) and stainless steel (Samaranayake and Sastry 2005; Stancl and Zitny 2010; Suebsiri et al. 2019). Regarding the heated product/material, solid and dry agricultural materials cannot be heated using ohmic heating. Meanwhile, for wet materials (high moisture content), particulates or liquids, the heating rate is affected by the EC of the material. The greater the EC of the material, the faster the heating process; otherwise, if the EC of the material is small or does not have EC, electricity cannot flow, and heating does not occur (Sakr and Liu 2014). Thus, before applying ohmic heating to a process, it is necessary to observe the EC value of the processed material. Several studies have revealed variations in the EC value of an ingredient ranging from pure water with a very low EC value of 0.0055 $mS \cdot m^{-1}$ (Sakr and Liu 2014), seawater in the range of 5.5 to 39.9 $S \cdot m^{-1}$ (Assiry et al. 2010), apples concentrates in the range of 0.4 to 1.0 $S \cdot m^{-1}$ (Icier and Ilicali 2004), milk in the range of 0.59 to 1.32 (Suebsiri et al. 2019), coffee bean with mucilage around 0.05 $S \cdot m^{-1}$ (Sagita et al. 2022). According to Kutz (2019), food materials with EC in the range of 0.01–10 $S \cdot m^{-1}$ are suitable for ohmic heating applications.

Several recent studies related to ohmic heating in recent years include pasteurisation and sterilisation (Achir et al. 2016; Cho et al. 2017), drying and pre-drying (Hosainpour et al. 2014; Torshizi et al. 2020), cooking of several products (Ding et al. 2021; Gratz et al. 2021), evaporation of fruit concentrate (Sabanci et al. 2019; Sabanci 2021), thawing (Çokgezme et al. 2021), bread baking (Gally et al. 2016; Khodeir et al. 2021), extraction processes (Al-Hilphy et al. 2020), fermentation (Reta et al. 2017; Salengke et al. 2021) and even water distillation (Abdulstar et al. 2022). Ohmic heating is conducive to improving functional properties, digestion, and absorption of soybean milk protein, fruit, and vegetable products (Li et al. 2018). Cooking rice with ohmic heating does not cause dirt to stick to the container (Kanjanapongkul 2017). In fermentation, ohmic heating can reduce the microbial lag phase, speeding up the fermentation time (Gavahian and Tiwari 2020).

With the increasing demand for the application of ohmic heating for various purposes, it is very important to develop an ohmic heating apparatus that can be used to support various applications in food and agricultural research. Previous studies have developed several types of ohmic heating equipment, but their application is specific to a particular process. Some of the ohmic heating designs that had been developed were the ohmic heating apparatus for the cocoa fermentation process (Supratomo et al. 2019) and the ohmic heating device for pasteurisation (Cho et al. 2017). Furthermore, there is no commercialised ohmic heating apparatus, especially at an affordable price. Based on this description, this study aims to develop a multipurpose ohmic heating apparatus equipped with various complementary features such as a temperature control system, a chamber that can be adjusted for the distance between the electrodes, and a data logging system as an essential thing, where the product temperature, ambient temperature, electrical current and voltage can be recorded at certain time intervals.

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## MATERIAL AND METHODS

The method used in developing the ohmic heating apparatus was the prototyping method, which consists of three stages, i.e., design criteria collection, functional-structural analysis, 3D designs and system architecture, prototype manufacturing, and performance testing. The materials used for constructing the equipment were selected based on material properties, availability, machinability, and economic considerations. Material properties were considered based on the strength of the materials, toughness, stiffness, heat resistance and corrosion resistance.

**Design consideration.** The main purpose of the ohmic heating apparatus is to perform several processes based on the ohmic principle, which is a uniform heating method and high energy efficiency (Sakr and Liu 2014). Some feature considerations should be made regarding the ohmic heating equipment to obtain the appropriate apparatus design. The design criteria consist of: (*i*) the ohmic heating apparatus should be able to perform several processes (pasteurisation, cooking, warming and fermentation) (*ii*) the apparatus should be able to perform three individual operations (treatments) in one running, (*iii*) the distance between the electrodes in the chamber should be adjustable, (*iv*) the apparatus should be equipped with a temperature and voltage setpoint control system, (*v*) the data from each sensor, i.e. temperature sensors, humidity-temperature sensor, electrical current sensors, and voltage sensors should be monitored via a liquid-crystal display (LCD), (*vi*) the parameter data of temperature, electrical current, and voltage should be stored on a memory card, (*vii*) the apparatus should be mobilised easily. Based on the design consideration, functional analysis was performed to describe the main function and subfunction then was derived to the required components that were chosen for fabricating the prototype. The result of the functional analysis of the ohmic heating apparatus is shown in Table 1.

All parts of the ohmic heating apparatus were constructed and placed on the main frame. There were three independent ohmic units (three chambers) that can be operated parallelly and individually, thus three different treatments can be performed together in a single running process. It was crucial to provide three individual units, especially for research purposes that required a long duration of a process such as fermentation based on the ohmic heating principle. This can save time and ensure the material is processed in the same state (homogeneous).

Based on the analysis of sub-functions and material requirements, the design stage was carried out to compile the structure and visualise it in the form of a 3D design using CAD software (Solidworks version 2021). The design of the ohmic heating apparatus in isometric form and exploded view is presented in Figure 1.

Based on Figure 1, there were 3 series of chambers in one process room. Each chamber was designed

Table 1. Functional analysis of a multipurpose ohmic heating apparatus with a real-time data logging system

| Main function | Sub function | Component |
|---|---|---|
| Performed ohmic heating-based processing and recorded some parameter data (voltage, current, product temperature and ambient humidity temperature) with real time | propping up the parts of the ohmic heating components | cubic steel bar with material of SS314 |
| | placing the products or materials that will be processed by ohmic heating | chamber with heat and corrosion-resistant material |
| | transmitting the electrical power into the product | Stainless steel electrode (SS314) |
| | setting up the operational voltage | variable voltage transformer |
| | setting up and controlling the temperature | microcontroller (Arduino Mega) and relay module |
| | measuring the voltage, electrical current, product temperature, and ambient humidity-temperature | ZMPT101B sensor for voltage; ACS712 sensor for electrical current; DS18b20 sensor for product temperature; DHT22 sensor for ambient humidity-temperature |
| | recording the measurement data with real time | memory cards shield module with real-time clock module build for Arduino |
| | displaying the measurement data | LCD (4×20 characters) |

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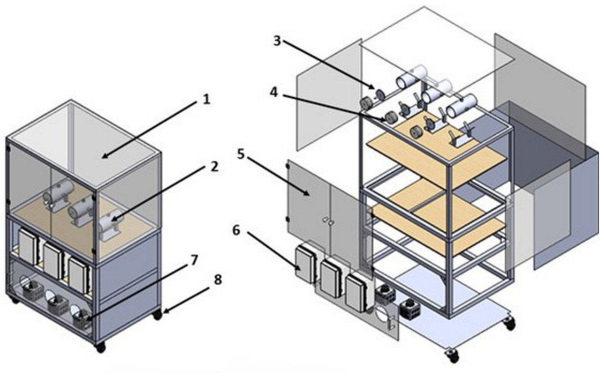


Figure 1. Isometric and exploded view of the developed ohmic heating apparatus
1 – processing room; 2 – ohmic heating chamber; 3 – electrode; 4 – chamber cover; 5 – door; 6– control panel; 7 – voltage regulator; 8 – mobilisation wheel

so that the distance between the electrodes could be adjusted. Thus, the design was made as shown in Figure 2. This apparatus was made for laboratory-scale experimental testing, and the maximum processing capacity in each chamber was 1 000 mL of material.

Based on Figure 2, the chamber was cylindrical with an inner diameter of 90 mm. The temperature sensor was placed in the middle of the chamber and a pair of electrodes were placed on both sides. The electrode material was food-grade stainless steel (SS 316) with a diameter of 0.5 mm smaller than the inner diameter of the chamber. At the electrodes, there was a 70 mm long shaft with a diameter of 6 mm for connecting to a power source. The electrodes were protected with Teflon material as an insulator and were equipped with 2 heat-resistant rubber rings on each Teflon to avoid leakage.

**System architecture.** In this ohmic heating apparatus, a data logging system was embedded to measure and record several parameter data. A block diagram of this apparatus is shown in Figure 3. It can be seen that several sensors were used to measure several variables, i.e., product temperature, ambient humidity temperature, voltage, and electrical current. Product temperature sensors were placed at the center of the chamber and could be attached and detach easily. Ambient humidity-temperature sensors were placed outside of the chamber and inside the room process. Voltage sensors and electrical current sensors were placed in the panel box near the microcontroller. A schematic diagram of the components used for the data logging system is presented in Figure 4.

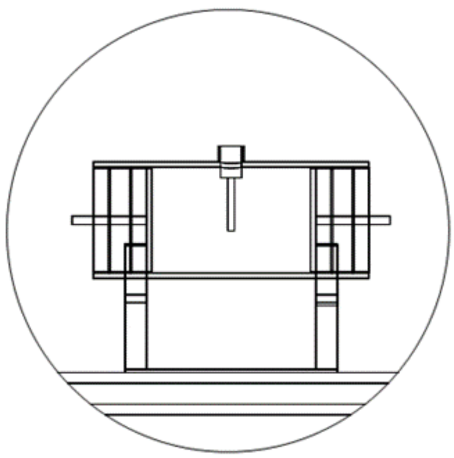

Figure 2. Chamber design with adjustable electrode spacing

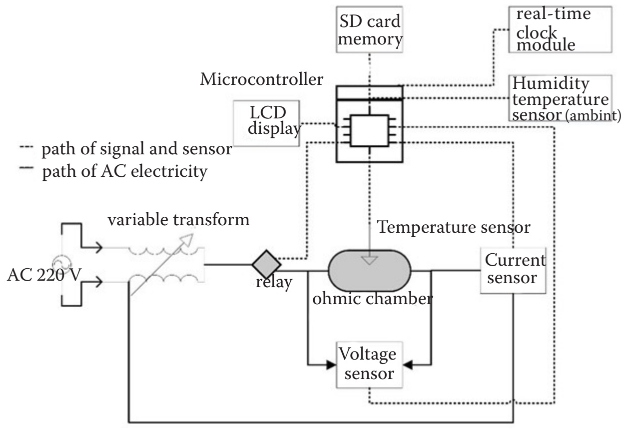


Figure 3. block diagram of ohmic heating apparatus with a data logging system

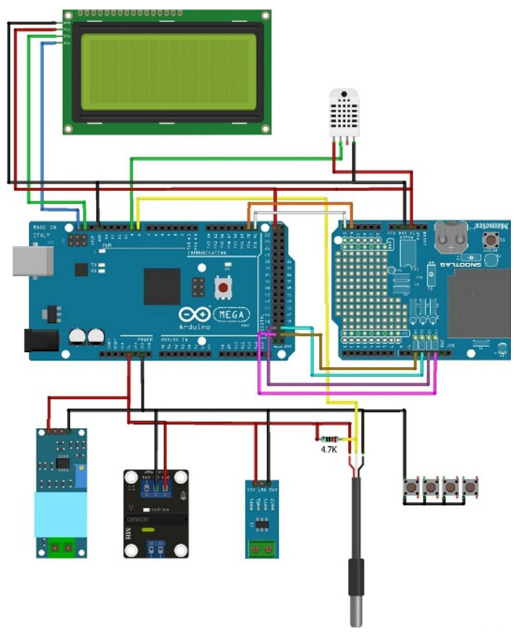

Figure 4. Schematic of electrical components used for a data logging system

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**Sensor reading performance.** Performance tests of sensor measuring system were performed between sensor and commercial standard instrument. The temperature was compared with DaqPRO 5300 instrument equipped with PT100 sensor (Fourtec, USA). Voltage and electrical current were compared with a kWh meter type P06S-100 (Yueqing NQQk Electric Factory, China). The accuracy of the sensor was evaluated by calculating the mean absolute error (MAE), mean absolute percentage error (MAPE), and coefficient of determination ($R^2$). *MAE*, *MAPE*, and $R^2$ were calculated using Equations 1–3.

$$MAE = \frac{\sum_{i=1}^{n}\left|y_i - \hat{y}_l\right|}{n} \tag{1}$$

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\frac{\left|y_i - \hat{y}_l\right|}{y_i}\times 100\% \tag{2}$$

$$R^2 = \frac{\sum_{k=1}^{n}\left(y_i - \hat{y}_l\right)^2}{\sum_{k=1}^{n}\left(y_i - y_l\right)^2} \tag{3}$$

where: $y_i$ – data obtained from sensor reading; $\hat{y}_l$ – data obtained from the commercial standard instrument reading; $y_e$ – the mean of all $\hat{y}$ data.

**Performance of control system and data logging system.** Performance tests were performed on the ohmic heating apparatus to evaluate the control and data logging systems. The material used as a heating product was mineral water. The deviation between actual temperature and setpoint temperature was calculated to evaluate the control system. To evaluate the data logging system, the recorded data from the SD card in the form of a CSV file was presented. The performance tests were carried out in three replications.

**Data analysis.** Evaluation for comparing sensor measurement with the standard instrument was performed from 5 to 30 repetitions depending on the type of sensor. DHT sensor testing (temperature-humidity) was performed in 5 repetitions with a temperature range of 26–39 and humidity between 75–97%. The DS18b20 temperature sensor was tested in 10 repetitions with a temperature range of 11–66. Testing of the ACS712 current sensor was carried out in 30 repetitions with a current range from 0.05 to 0.88 A. Testing of the ZMPt101b voltage sensor was carried out in 16 repetitions with an electric range from 0 to 220 V. Data were analysed statistically to obtain *MAE*, *MAPE* and $R^2$ values from each result sensor testing. The smaller the *MAE* and *MAPE* values indicate the more accurate the sensor is, and the greater the $R^2$ value (close to 1) indicates the greater the sensor correlation with standard instruments.

## RESULT AND DISCUSSION

**Prototype of a multipurpose ohmic heating apparatus with data logging system.** A prototype of a multipurpose ohmic heating apparatus with a data logging system has been successfully designed and fabricated based on design criteria. This device processed three samples with different treatments in one run. The prototype consisted of the main frame, process room, chamber, panel box, variable voltage transformer, and driving motor. The prototype is visually described in Figure 5. The overall dimension is 1 000 × 1 000 × 1 500 mm.

Figure 5. Prototype of a multipurpose ohmic heating apparatus with data logging system

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Figure 6 presents the panel box for monitoring and setting up the ohmic heating apparatus. Inside the panel box was a series of temperature control systems and data recorders consisting of a microcontroller, automatic relay/switch, electric current sensor, voltage sensor, LCD monitor, and memory card to store data every 21 seconds. The LCD monitor showed several data, i.e., the chamber temperature, setpoint temperature, voltage, electric current, and room temperature-humidity.

**Performance of sensor measurement.** The sensors used in the apparatus were tested by comparing the sensor readings with the standard instrument readings (commercial instrument). The accuracy sensor was evaluated using *MAE* and *MAPE*. Table 2 presents each sensor's calculation results of *MAE*, *MAPE* and $R^2$. The smaller the *MAE* and *MAPE* values (close to zero), the higher the sensor accuracy.


Figure 6. Panel box for monitoring and setting up the ohmic heating system

The first type of sensor was a voltage sensor (ZMPT101B), which was compared with the measurement from the kWh meter type P06S-100 (Yueqing NQQk Electric Factory, China). Table 2 shows that the voltage sensor's measurement results gave MAE values of 0.2–0.8 V, MAPE 0.1–0.6%, and $R^2$ close to 1, which means that the sensor measurement results have very good regression values with standard instruments. This value was satisfactory because the error that occurred was very small. Thus, implementing the ZMPT101B sensor as a voltage measurement module in the ohmic heating apparatus provided a very good measurement accuracy. Previous research found that voltage harmonics error percentage measured by ZMPT101B was 3.7% in the case of the MECO meter and 1.52% in the case of the Fluke 434 m (Kumar et al. 2021). As per Institute of Electrical and Electronics Engineers (IEEE) Stdandard 3002.8-2018, the harmonic voltage distortion limit is 8% total harmonic distortion (THD) for less than 1kV (Kumar et al. 2021).

The second sensor is the electrical current sensor (ACS712). The current sensor also consisted of 3 sensors that measure the electric current that enters the ohmic heating chamber. The comparison instrument used was the same as the comparison instrument for measuring voltage, i.e., the kWh meter type P06S-100. Based on the measurement data from the current range of 0.03 A to 0.8 A, the sensor has a high linearity level with a very high $R^2$ value between 0.9991–0.9995. In addition, Table 2 shows

Table 2. Result of the sensor measurement performance

| Parameter | Sensor's name | Commercial measuring instrument | *MAE* | *MAPE* (%) | $R^2$ |
|---|---|---|---|---|---|
| Voltage (V) | ZMPT101B (sensor 1) | kWh meter type P06S-100 (Yueqing NQQk Electric Factory, China) | 0.8 | 0.6 | 1 |
| | ZMPT101B (sensor 2) | | 0.2 | 0.1 | 1 |
| | ZMPT101B (sensor 3) | | 0.7 | 0.5 | 1 |
| Electric current (A) | ACS712 (sensor 1) | kWh meter type P06S-100 (Yueqing NQQk Electric Factory, China) | 0.01 | 3.1 | 0.999 |
| | ACS712 (sensor 2) | | 0.02 | 5.4 | 0.999 |
| | ACS712 (sensor 3) | | 0.01 | 2.7 | 0.999 |
| Temperature (°C) | DS18b20 (sensor 1) | DaqPro 5300 equipped with PT100 probe (Omega Engineering, USA) | 0.2 | 0.7 | 1 |
| | DS18b20 (sensor 2) | | 0.3 | 1.1 | 1 |
| | DS18b20 (sensor 3) | | 0.3 | 0.9 | 1 |
| Room humidity (%) | DHT22 | handheld temperature/humidity meter (Omega Engineering, USA) | 0.3 | 0.8 | 0.999 |
| | DHT22 | | 0.8 | 1.0 | 0.999 |

*MAE* – mean absolute error; *MAPE* – mean absolute percentage error; $R^2$ – coefficient of determination

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that the *MAE* value ranges from 0.01 to 0.02 A and the *MAPE* value ranges from 2.7 to 5.4%. This value was also very small because it was below 6%, thus the measurement value could be trusted. This result aligns with previous research that uses ACS712 sensor, where the relative error for the current measurement range was less than 5% (Dabou et al. 2021). This error was greater than indicated in the datasheet because the sensor was affected by temperature (Dabou et al. 2021). Another research also found that the *MAE* obtained from the validation of the ACS712 sensor was lower than 0.05 A (Jabbar et al. 2022).

The third sensor was the temperature sensor of the heated material, using DS18b20 type sensor. This sensor was suitable for the application of both liquid and particulate materials because it was covered with a stainless-steel material. Thus, it was corrosion resistant. This sensor was suitable for ohmic heating due to the sensor chip was not directly attached to stainless steel, but coated with a material did not transmit electricity, so it would not be disturbed by the electricity flow in the ohmic heating chamber. The performance of sensor measurement was compared with the DaqPro 5300 instrument (Omega Engineering, USA). Based on Table 2, the three temperature sensors provided a very high $R^2$ value close to 1. The data measurement range was 10–70 °C. In addition, the MAE value of the three sensors was 0.2–0. °C and the MAPE was 0.7–1.1%. The results of this measurement were very satisfying because the error that occurred was very small. This was also in line with previous research that reported that the accuracy of the DS18b20 was ± 0.5°C (Obando Vega et al. 2020). Thus, this sensor was very good to be applied to an ohmic heating apparatus as a data acquisition system for measuring the temperature of the product during ohmic heating. According to (Obando Vega et al. 2020), the use of the DS18B20 sensor was recommended over the internal IR sensor due to its lower acquisition and installation costs.

The fourth sensor used as a module for data acquisition on this ohmic heating apparatus was the humidity-temperature sensor (DHT22). This sensor was useful for measuring temperature and humidity in the room where the three ohmic heating chambers operate, so only one sensor unit is needed. The temperature and humidity measurement results were compared with a standard measuring instrument, namely a handheld temperature/humidity meter (Omega Engineering, USA). Based on Table 2, the temperature and humidity between the sensor and the standard instrument showed a linear relationship with $R^2$ approaching 1. In addition, the *MAE* of the temperature reading value was also very small, about 0.3°C (*MAPE* 0.8%), and the *MAE* of the humidity reading was 0.8% (*MAPE* 1.0%). The DHT22 sensor was widely applied because it was cheap and had better accuracy than DHT11. Some of its applications include monitoring temperature and humidity in the incubator and the environmental condition (Kho et al. 2022; Peprah et al. 2022).

Overall, the data measurement system in the ohmic heating apparatus has a high level of accuracy. Thus, it can be used for various applications where the data during the process can be measured properly and accurately.

**Performance of control system and data logging system.** The performance of the control system was evaluated based on the results of the whole system in controlling the temperature according to the set points that have been chosen. This Ohmic heating apparatus worked based on the temperature set at the beginning of the process. Thus, various processes can be applied using this apparatus, from those requiring low temperatures, such as fermentation, warming and preheating, to higher temperatures, such as cooking and pasteurisation. In this study, the control system was tested in a temperature range for warming/fermentation purposes. 40 °C.

The performance of the system in controlling the temperature is presented in Figure 7. Based on Figure 7, the temperature curve increased to a set point of 40 °C, then held constant until the end of the process. This can also be seen from the electric current curve where since the target temperature was reached, the current was cut off, and the current value measured by the sensor was 0 A; while the temperature dropped, the electric current flowed again so that the temperature rose again. In the graph, it can be seen that the electric current changed between on and off. Descriptive analysis of temperature data is presented in Table 3, where the average temperature after the set point is reached for trials 1, 2 and 3 are 39.98±0.03 °C, 39.99±0.02 °C and 39.99±0.02 °C respectively. This research was in line with previous research, which claimed that the standard deviation of the temperature control system in ohmic heating for coffee fermentation showed a very small value ranging from 0.04 to 0.16 °C (Sagita et al. 2022). It was revealed that the developed apparatus had performed even better in maintaining the tempera-

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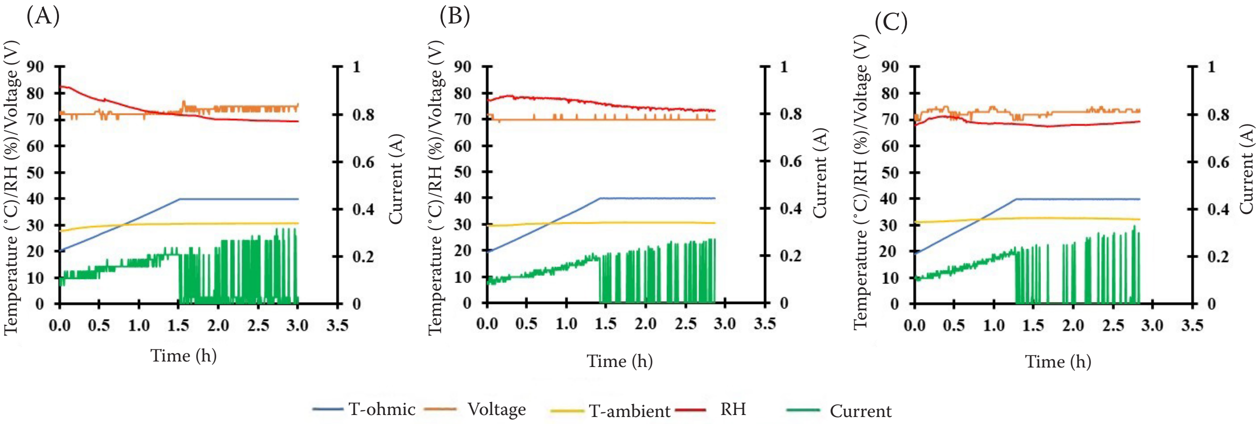



Figure 7. data display since the set point temperature was reached: (A) trial 1, (B) trial 2, and (C) trial 3
RH – relative humidity

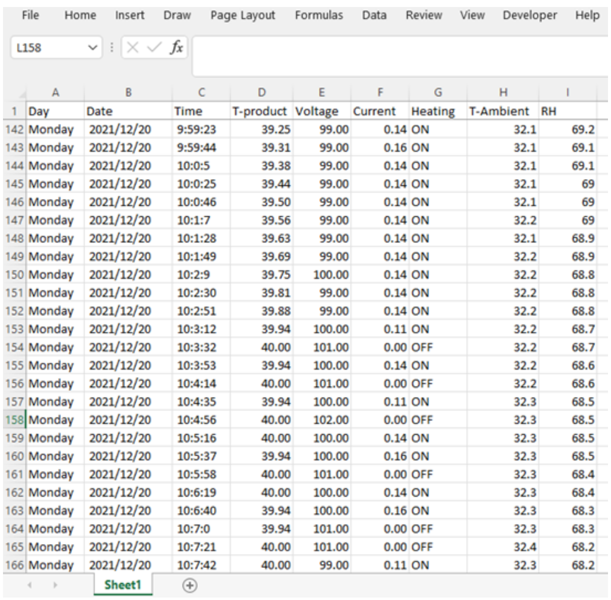
Table 3. Descriptive analysis of the temperature sensor after set point was reached (°C)

| Trial | *N* | Average temp | Max temp | Min temp. | SD | SE mean |
|---|---|---|---|---|---|---|
| 1 | 101 | 39.98 | 40.00 | 39.94 | 0.03 | 0.003 |
| 2 | 101 | 39.99 | 40.06 | 39.94 | 0.02 | 0.002 |
| 3 | 101 | 39.99 | 40.06 | 39.94 | 0.02 | 0.002 |

*N* – number of data; SD – standard deviation; SE – standard error

ture of the processed material because the deviation was below 0.03 °C. Furthermore, the voltage sensor also worked well in measuring data, where the curve was very stable according to the initial voltage given, which was 72 V.

The performance of the data logging system can be seen in Figure 8. This picture was an example of data recorded by the microcontroller and saved to the SD card memory in CSV format. Figure 8 was also displayed only when the temperature started reaching the set point of 40°C. It can be seen that the recorded parameters were essential, starting with the day, date, hour, material temperature, voltage, electric current, heating conditions, and environmental temperature-humidity. Thus, the control system on the ohmic heating apparatus has been well operated and satisfactorily. Thus, the data during the apparatus work can be recorded. The data can be useful for research and further analysis.




| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Day | Date | Time | T-product | Voltage | Current | Heating | T-Ambient | RH |
| 142 | Monday | 2021/12/20 | 9:59:23 | 39.25 | 99.00 | 0.14 | ON | 32.1 | 69.2 |
| 143 | Monday | 2021/12/20 | 9:59:44 | 39.31 | 99.00 | 0.16 | ON | 32.1 | 69.1 |
| 144 | Monday | 2021/12/20 | 10:0:5 | 39.38 | 99.00 | 0.14 | ON | 32.1 | 69.1 |
| 145 | Monday | 2021/12/20 | 10:0:25 | 39.44 | 99.00 | 0.14 | ON | 32.1 | 69 |
| 146 | Monday | 2021/12/20 | 10:0:46 | 39.50 | 99.00 | 0.14 | ON | 32.1 | 69 |
| 147 | Monday | 2021/12/20 | 10:1:7 | 39.56 | 99.00 | 0.14 | ON | 32.2 | 69 |
| 148 | Monday | 2021/12/20 | 10:1:28 | 39.63 | 99.00 | 0.14 | ON | 32.1 | 68.9 |
| 149 | Monday | 2021/12/20 | 10:1:49 | 39.69 | 99.00 | 0.14 | ON | 32.2 | 68.9 |
| 150 | Monday | 2021/12/20 | 10:2:9 | 39.75 | 100.00 | 0.14 | ON | 32.2 | 68.8 |
| 151 | Monday | 2021/12/20 | 10:2:30 | 39.81 | 99.00 | 0.14 | ON | 32.2 | 68.8 |
| 152 | Monday | 2021/12/20 | 10:2:51 | 39.88 | 99.00 | 0.14 | ON | 32.2 | 68.8 |
| 153 | Monday | 2021/12/20 | 10:3:12 | 39.94 | 100.00 | 0.11 | ON | 32.2 | 68.7 |
| 154 | Monday | 2021/12/20 | 10:3:32 | 40.00 | 101.00 | 0.00 | OFF | 32.2 | 68.7 |
| 155 | Monday | 2021/12/20 | 10:3:53 | 39.94 | 100.00 | 0.14 | ON | 32.2 | 68.6 |
| 156 | Monday | 2021/12/20 | 10:4:14 | 40.00 | 101.00 | 0.00 | OFF | 32.2 | 68.6 |
| 157 | Monday | 2021/12/20 | 10:4:35 | 39.94 | 100.00 | 0.11 | ON | 32.3 | 68.5 |
| 158 | Monday | 2021/12/20 | 10:4:56 | 40.00 | 102.00 | 0.00 | OFF | 32.3 | 68.5 |
| 159 | Monday | 2021/12/20 | 10:5:16 | 40.00 | 100.00 | 0.14 | ON | 32.3 | 68.5 |
| 160 | Monday | 2021/12/20 | 10:5:37 | 39.94 | 100.00 | 0.16 | ON | 32.3 | 68.5 |
| 161 | Monday | 2021/12/20 | 10:5:58 | 40.00 | 101.00 | 0.00 | OFF | 32.3 | 68.4 |
| 162 | Monday | 2021/12/20 | 10:6:19 | 40.00 | 100.00 | 0.14 | ON | 32.3 | 68.4 |
| 163 | Monday | 2021/12/20 | 10:6:40 | 39.94 | 100.00 | 0.16 | ON | 32.3 | 68.3 |
| 164 | Monday | 2021/12/20 | 10:7:0 | 39.94 | 101.00 | 0.00 | OFF | 32.3 | 68.3 |
| 165 | Monday | 2021/12/20 | 10:7:21 | 40.00 | 101.00 | 0.00 | OFF | 32.4 | 68.2 |
| 166 | Monday | 2021/12/20 | 10:7:42 | 40.00 | 99.00 | 0.11 | ON | 32.3 | 68.2 |

Figure 8. display of the recorded data by data logging system

**Performance of measurement durability.** The durability performance of the apparatus was evaluated to assess its reliability during continuous usage for up to 24 hours. Figure 9 illustrates the data the data logging system recorded over multiple hours, encompassing various parameters such as voltage, electrical current, product temperature, and ambient temperature-humidity. The product temperature remained consistently stable throughout the process, maintaining a linear curve at 40 **°C** for over 24 hours. The electric current operated intermittently, resulting in periodic rises and falls between 0 and approximately 0.27 A. Although there was minimal noise, the data can still be processed for further analysis, if necessary.

Furthermore, the ambient temperature in the room displayed fluctuations corresponding to environmental conditions, with recorded values ranging between 28 to 32°C. This observation indicates that the ohmic heating system functioned effectively, maintaining

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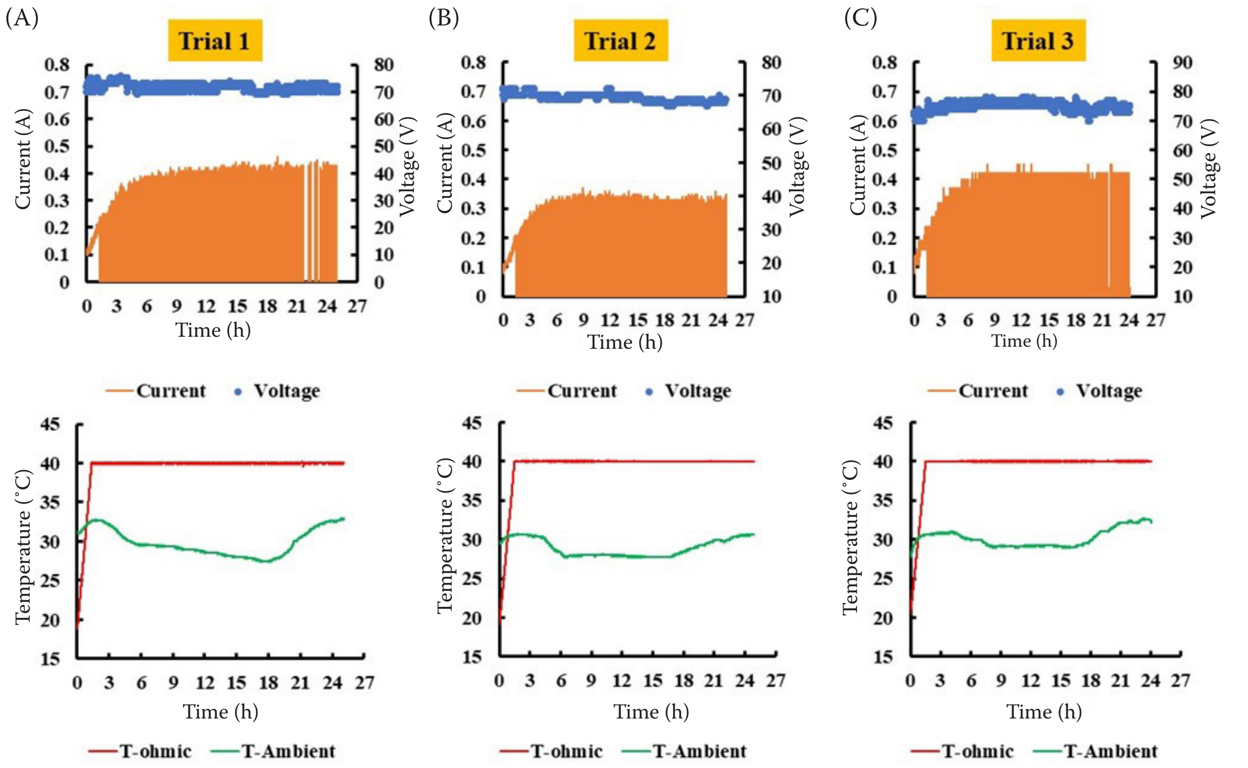


Figure 9. Result of data logging system for 24 hours non-stop operation of ohmic heating apparatus: (A) trial 1, (B) trial 2, and (C) trial 3

the desired temperature within the chamber regardless of external factors. The measured voltage data was generally satisfactory, despite minor fluctuations that can be attributed to the inherent variability of electrical flow. Such fluctuations are normal and have been documented in the literature.

Based on durability tests mentioned in the literature, which involve cycling, or turning equipment on and off at regular intervals and for specified lengths of time (Benson et al. 2013), the developed ohmic apparatus has demonstrated its capability to operate continuously for 24 hours. The sensor successfully recorded data at a rate of (1/20 cycle/sec) × 60 s/min × 60 min/h × 24 h, resulting in a total of 4 320 data points. This process was repeated three times, consistently yielding accurate measurement and data recording results. According to a study conducted by Elyounsi and Kalashnikov (2021), experimental readings were performed for approximately three months. The readings of DS18b20 showed excellent agreement with an average bias of only 0.05 °C and most scattered within ± 0.08 °C. The experiment gave them confidence in the accuracy of the DS18B20 sensors for measuring in the long-term condition. Then a Medina-Garcia et al. (2017) study used the ACS712 sensor. The results show very low power consumption, low cost, highly reliable and compact design, achieving a high level of autonomy for over two years with only one 3.3 V/2600 mAh battery. Another study used ZMPT101b, AC712 and Arduino as microcontrollers to develop a grounding status detection tool (Corio et al. 2022). The results showed that the tool's duration reaches 10 h non-stop per day, which is a long enough time to use for checking the grounding condition of a building.

Based on the overall testing and supported by several previous studies, the use of low-cost sensors (ZMPT101b, ACS712 and DS18b20) was suitable for developing the ohmic heating apparatus with good quality measurement and durability. This device and its supporting systems operated effectively and can be utilised for various research and development purposes related to ohmic heating applications. The apparatus is well-suited for processes requiring extended durations, such as fermentation, temperature conditioning, and storage, as long as the materials involved meet the necessary electrical conductivity criteria to leverage the benefits of ohmic heating principles.

https://doi.org/10.17221/21/2023-RAE

## CONCLUSION

An apparatus of a multipurpose ohmic heating system integrated with a data logging system was designed, fabricated, and tested. The apparatus was constructed by combining several low-cost sensors consisting of voltage sensors (ZMPT101B), electrical current sensors (ACS712), temperature sensors (DS18b20), and temperature-humidity sensors (DHT22). The fabricated apparatus was validated by comparing the sensor reading with commercial instruments. The *MAE* and *MAPE* of the voltage sensor were 0.2–0.8 V and 0.12–0.6%, respectively; the electrical current sensor was 0.01–0.02 A and 2.7–5.4%, respectively; the temperature sensor was 0.2–0.3°C and 0.7–1.1%, respectively; and humidity sensor was 0.8% and 1%, respectively. The apparatus was also tested for the control and data logging systems. The product temperature could be accurately maintained according to the set point temperature with a deviation value lower than 0.1 °C. The data logging system was able to record and store the parameter data in SD card memory for up to several days without interruption. The results demonstrated that the developed apparatus can be used for several heating processes of food and agricultural materials based on the ohmic heating principle.

**Acknowledgement**: The authors would like to thank everyone from the Research Center for Appropriate Technology, National Research and Innovation Agency, especially to Teguh Santoso, Suhaya, Taufik Yudhi, Edi Jaenudin, Dadang Gandara, Iman Rusim, Beni Guna Paksi, and Roni who have assisted in fabricating the prototype

## REFERENCES

Abdulstar A.R., Altemimi A., Al-HiIphy A.R.S., Watson D.G., Lakhssassi N. (2022): Water distillation using an ohmic heating apparatus. International Journal of Ambient Energy, 43: 1–11.

Achir N., Dhuique-Mayer C., Hadjal T., Madani K., Pain J.P., Dornier M. (2016): Pasteurization of citrus juices with ohmic heating to preserve the carotenoid profile. Innovative Food Science and Emerging Technologies, 33: 397–404.

Al-Hilphy A.R., Al-Musafer A.M., Gavahian M. (2020): Pilot-scale ohmic heating-assisted extraction of wheat bran bioactive compounds: Effects of the extract on corn oil stability. Food Research International, 137: 109649.

Assiry A.M., Gaily M.H., Alsamee M., Sarifudin A. (2010): Electrical conductivity of seawater during ohmic heating. Desalination, 260: 9–17.

Athmaselvi K.A., Kumar C., Poojitha P. (2017): Influence of temperature, voltage gradient and electrode on ascorbic acid degradation kinetics during ohmic heating of tropical fruit pulp. Journal of Food Measurement and Characterization, 11: 144–155.

Benson E., Hougentogler D., McGurk J., Herrman E., Alphin R. (2013): Durability of incandescent, compact fluorescent, and light emitting diode lamps in poultry conditions. Applied Engineering in Agriculture, 29: 103–111.

Bhargava N., Mor R.S., Kumar K., Sharanagat V.S. (2021): Advances in application of ultrasound in food processing: A review. Ultrasonics Sonochemistry, 70: 105293.

Chizoba Ekezie F.-G., Sun D.-W., Cheng J.-H. (2017): A review on recent advances in cold plasma technology for the food industry: Current applications and future trends. Trends in Food Science & Technology, 69: 46–58.

Cho W.I., Kim E.J., Hwang H.J., Cha Y.H., Cheon H.S., Choi J.B., Chung M.S. (2017): Continuous ohmic heating system for the pasteurization of fermented red pepper paste. Innovative Food Science and Emerging Technologies, 42: 190–196.

Çokgezme Ö.F., Döner D., Çevik M., Kemahlıoğlu A.V., İçier F. (2021): Influences of sample shape, voltage gradient, and electrode surface form on the exergoeconomic performance characteristics of ohmic thawing of frozen minced beef. Journal of Food Engineering, 307: 110660.

Corio D., Andanu R.A., Miranto A., Pratama R.W. (2022): Rancang Bangun Alat Pendeteksi Status Pentanahan pada Instalasi Listrik Bangunan Berbasis Arduino Mega 2650 Pro. ELECTRON Jurnal Ilmiah Teknik Elektro, 3: 49–57.

Cozzens S., Gatchair S., Kang J., Kim K.-S., Lee H.J., Ordóñez G., Porter A. (2010): Emerging technologies: quantitative identification and measurement. Technology Analysis & Strategic Management, 22: 361–376.

Dabou R., Bouraiou A., Ziane A., Necaibia A., Sahouane N., Blal M., Khelifi S., Rouabhia A., Slimani A. (2021): Development of autonomous monitoring and performance evaluation system of grid-tied photovoltaic station. Sustainable Energy and Environmental Protection, 46: 30267–30287.

Ding X., Liu J., Xiong X., Wang S., Li X. (2021): Influence of ohmic heating on the electrical conductivity, volume, and rice quality of each component of the water–rice mixture. Innovative Food Science and Emerging Technologies, 72: 102757.

El Kantar S., Koubaa M. (2022): Pulsed electric field treatment for the stimulation of microorganisms: Applications in food production. Research in Agricultural Engineering, 68: 80–92.

https://doi.org/10.17221/21/2023-RAE

Elyounsi A., Kalashnikov A.N. (2021): Evaluating suitability of a DS18B20 temperature sensor for use in an accurate air temperature distribution measurement network. Engineering Proceedings, 10: 56.

Faruk O., Sabanci S., Cevik M., Yildiz H., Icier F. (2017): Performance analyses for evaporation of pomegranate juice in ohmic heating assisted vacuum system. Journal of Food Engineering, 207: 1–9.

Gally T., Rouaud O., Jury V., Le-Bail A. (2016): Bread baking using ohmic heating technology; a comprehensive study based on experiments and modelling. Journal of Food Engineering, 190: 176–184.

Gavahian M., Tiwari B.K. (2020): Moderate electric fields and ohmic heating as promising fermentation tools. Innovative Food Science and Emerging Technologies, 64: 102422.

Gratz M., Schottroff F., Gall L., Zejma B., Simon F., Jaeger H. (2021): Advantages of ohmic cooking in the kilohertz-range - part I: Impact of conductivity and frequency on the heating uniformity of potatoes. Innovative Food Science and Emerging Technologies, 67: 102595.

Hosainpour A., Darvishi H., Nargesi F., Fadavi A. (2014): Ohmic pre-drying of tomato paste. Food Science and Technology International, 20: 193–204.

Icier F., Ilicali C. (2004): Electrical conductivity of apple and sourcherry juice concentrates during ohmic heating. Journal of Food Process Engineering, 27: 159–180.

Jabbar W.A., Annathurai S., A. Rahim T.A., Mohd Fauzi M.F. (2022): Smart energy meter based on a long-range wide-area network for a stand-alone photovoltaic system. Expert Systems with Applications, 197: 116703.

Kanjanapongkul K. (2017): Rice cooking using ohmic heating: Determination of electrical conductivity, water diffusion and cooking energy. Journal of Food Engineering, 192: 1–10.

Kho E.P., Chua S.N.D., Lim S.F., Lau L.C., Gani M.T.N. (2022): Development of young sago palm environmental monitoring system with wireless sensor networks. Computers and Electronics in Agriculture, 193: 106723.

Khodeir M., Rouaud O., Ogé A., Jury V., Le-Bail P., Le-Bail A. (2021): Study of continuous cake pre-baking in a rectangular channel using ohmic heating. Innovative Food Science and Emerging Technologies, 67.

Kumar L.A., Indragandhi V., Selvamathi R., Vijayakumar V., Ravi L., Subramaniyaswamy V. (2021): Design, power quality analysis, and implementation of smart energy meter using internet of things. Computers & Electrical Engineering, 93: 107203.

Kutz M. (2019): Handbook of farm, dairy and food machinery engineering, Academic Press.

Li X., Ye C., Tian Y., Pan S., Wang L. (2018): Effect of ohmic heating on fundamental properties of protein in soybean milk. Journal of Food Process Engineering, 41: e12660.

Marra F., Zell M., Lyng J.G., Morgan D.J., Cronin D.A. (2009): Analysis of heat transfer during ohmic processing of a solid food. Journal of Food Engineering, 91: 56–63.

Obando Vega F.A., Montoya Ríos A.P., Osorio Saraz J.A., Vargas Quiroz L.G., Alves Damasceno F. (2020): Assessment of black globe thermometers employing various sensors and alternative materials. Agricultural and Forest Meteorology, 284: 107891.

Parniakov O., Lebovka N., Wiktor A., Comiotto Alles M., Hill K., Toepfl S. (2022): Applications of pulsed electric fields for processing potatoes: Examples and equipment design. Research in Agricultural Engineering, 68: 47–62.

Peprah F., Gyamfi S., Amo-Boateng M., Buadi E., Obeng M. (2022): Design and construction of smart solar powered egg incubator based on GSM/IoT. Scientific African, 17: e01326.

Reta R., Mursalim M., Salengke S., Muhidong J., Bilang M., Sopade P. (2017): Reducing the acidity of arabica coffee beans by ohmic fermentation technology. Food Research, 1: 157–160.

Sabanci S. (2021): A study on electrical conductivity and performance evaluation of ohmic evaporation process of grape juice. Journal of Food Processing and Preservation, 45: e15487.

Sabanci S., Icier F. (2017): Applicability of ohmic heating assisted vacuum evaporation for concentration of sour cherry juice. Journal of Food Engineering, 212: 262–270.

Sabanci S., Cevik M., Cokgezme O.F., Yildiz H., Icier F. (2019): Quality characteristics of pomegranate juice concentrates produced by ohmic heating assisted vacuum evaporation. Journal of the Science of Food and Agriculture, 99: 2589–2595.

Sagita D., Doddy A.D., Hidayat D.D. (2021): Recent studies and prospective application of ohmic heating for fermentation process: a mini-review. E3S Web of Conferences. EDP Sciences.

Sagita D., Setiaboma W., Kristanti D., Kurniawan Y.R., Hidayat D.D., Darmajana D.A., Sudaryanto A., Nugroho P. (2022): Experimental investigation of heating pattern, energy requirement and electrical conductivity in a batch ohmic heating system for coffee fermentation. Innovative Food Science & Emerging Technologies, 76: 102946.

Sakr M., Liu S. (2014): A comprehensive review on applications of ohmic heating (OH). Renewable and Sustainable Energy Reviews, 39: 262–269.

Salengke S., Hasizah A., Reta R., Mochtar A.A. (2021): Technology intervention to unleash the flavor potential of arabica coffee from Sulawesi highland. IOP Conference Series: Earth and Environmental Science, 807: 032009.

Samaranayake C.P., Sastry S.K. (2005): Electrode and pH effects on electrochemical reactions during ohmic heating. Journal of Electroanalytical Chemistry, 577: 125–135.

https://doi.org/10.17221/21/2023-RAE

Stancl J., Zitny R. (2010): Milk fouling at direct ohmic heating. Journal of Food Engineering, 99: 437–444.

Suebsiri N., Kokilakanistha P., Laojaruwat T., Tumpanuvatr T., Jittanit W. (2019): The application of ohmic heating in lactose-free milk pasteurization in comparison with conventional heating, the metal contamination and the ice cream products. Journal of Food Engineering, 262: 39–48.

Supratomo S., Laga A., Tahir M., Mochtar A.A., Salengke S. (2019): Design and performance test of ohmic-assisted cocoa fermentation apparatus. ARPN Journal of Engineering and Applied Sciences, 14: 1515–1523.

Torshizi M.V., Azadbakht M., Kashaninejad M. (2020): Application of response surface method to energy and exergy analyses of the ohmic heating dryer for sour orange juice. Fuel, 278: 118261.

Vorobiev E., Lebovka N. (2022): Processing of sugar beets assisted by pulsed electric fields. Research in Agricultural Engineering, 68: 63–79.

Received: February 7, 2023
Accepted: September 26, 2023
Published online: March 12, 2024