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Application of Fuzzy Control and IoT Monitoring on Small Scale Biofermentor for Making Virgin Coconut Oil

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ABSTRACT

Virgin Coconut Oil is a pure coconut oil that can be obtained from the extract of fresh and old coconut meat. This study aimed to evaluate the performance of a biofermentor integrated with a fuzzy logic control system and IoT for VCO production. The research involved designing control rules to regulate temperature, testing the IoT system for real-time monitoring, and assessing the biofermentor's performance. The parameters observed were control system response, temperature, yield and moisture content. Results showed that the fuzzy control system effectively maintained temperature stability, resulting in a higher yield (39.65%) and lower moisture content (0.08%) compared to conventional methods. In addition, the fuzzy control rules are able to regulate the power so that the temperature overshoot is quite small (1%), the settling time is relatively short (9 minutes), the temperature is stable, and the steady state error is 1.02% (with in tolerance limits).

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1. INTRODUCTION

Virgin Coconut Oil (VCO) is a highly valued product due to its numerous health and beauty benefits, including its antioxidant properties and ability to improve skin health. However, traditional VCO production methods often face challenges such as inconsistent temperature control, which can lead to variable product quality and lower yields. This study addresses these challenges by introducing a biofermentor equipped with a fuzzy logic control system and IoT for precise temperature regulation. VCO can be obtained from extracts of fresh and ripe coconut meat with an old fruit maturity level, because the oil content in old coconut fruit is more. The extraction method significantly influences the chemical composition, stability, nutritional quality, and shelf life of VCO. There are four main methods commonly used for VCO extraction: enzymatic extraction, cold pressing, centrifugation, and fermentation (Zainul, et al., 2024).

One of the traditional and cost-effective methods is fermentation. This method involves microbes to separate protein component and oil from coconut milk (Asmoro, et al., 2018). Although fermentation can result in higher levels of free fatty acids (FFA) and moisture, which can affect shelf life and stability, it still produces VCO that is not easily rancid, long-lasting, has a more fragrant aroma, and is almost cholesterol-free, but the drawback is in this method, the temperature used was not stable and has the potential to experience rancidity because it is stored at room temperature which can trigger the emergence of microbes that can damage the quality of VCO.

Temperature, as previously described, plays an important role in the production of VCO. Therefore, this variable needs to be controlled. Current technology is available, such as the use of microcontrollers to create control systems. Moreover, when combined with the use of IoT (Internet of Things), which now has integrated modules available, it can provide a cost-effective solution for real-time monitoring and efficient control (Fadil, et al., 2023). In this study, temperature control during the fermentation process will be conducted using a device called a biofermentor with a capacity of 15 liters. The control will use fuzzy logic with the expectation that the results will meet SNI (Indonesian National standard) No. 7381:2008.

2. MATERIALS AND METHODS

2.1. Materials

The biofermentor is used as a device to place the materials to be fermented, with the capability to control temperature. Additionally, to assist in the observation of parameters, an oven and a digital scale with 4-digit accuracy, a vacuum filter machine, a centrifuge machine, and an oil pump are used. Other supporting equipment includes containers, bottles, spoons, filter paper, and others. To control the temperature and transmit data for the monitoring system through IoT, Arduino Uno R3 and NodeMCU ESP8266 module were used with LM35 as the temperature sensor and an infrared lamp as the heater, which is actuated by an SSR. The biofermentor used is equipped with a stirrer to ensure the temperature is evenly distributed throughout the material. The focus of this research is on temperature control for heating the material using fuzzy logic control. The material being fermented is coconut milk.

2.2. Control and monitoring system design

It is essential to understand the system conditions through identification before designing the system, to determine the achievable temperature and system gain. The results of this system identification will be used to establish the fuzzy rules, where the output of these rules is the PWM setting to be sent to the SSR, which will determine the amount of power supplied to the heater, which is an infrared lamp.

The control system is developed in several stages: defining input/output, determining the universe of discourse, establishing membership functions and fuzzy sets, compiling control rules, and coding the controller on Arduino software. The monitoring process begins with pin initialization to set initial values for the pins used on the Arduino and ESP8266. The Arduino microcontroller connects to ESP8266 via serial communication on the Rx and Tx pins. At the designated send time, ESP8266 requests data from the Arduino module to be sent to the ThingSpeak server. To facilitate data transmission, the system must first connect to the internet. With Wi-Fi, the NodeMCU ESP8266 enables the connection between the system and ThingSpeak, allowing monitoring via a smartphone or laptop. The block diagram of the control and monitoring system is shown in Figure 1.

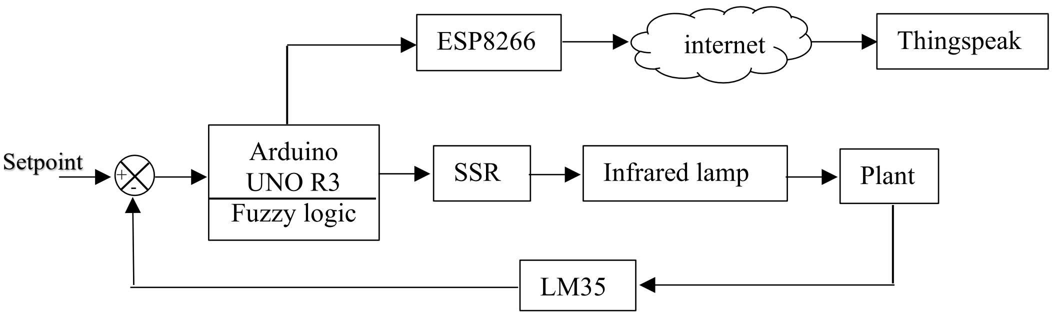

Figure 1. Block diagram of control and monitoring system.

2.3. Performance test

Testing is conducted by running the biofermentor with the inserted material, then observing temperature changes to understand the system's dynamic response for performance comparison, yield from biofermentor were compared with conventional method (without biofermentor). Parameters observed include overshoot and settling time. Once the temperature stabilizes at the setpoint, the steady-state response is observed to determine the error, targeting around 2-5% of the setpoint. For monitoring temperature data changes via IoT, the actual temperature displayed on the LCD is compared with the data on ThingSpeak, and the number of transmitted data points is observed to identify any data loss.

2.4. Data analysis

The yield of VCO can be determined by calculating the ratio of the weight of VCO produced to the weight of cream used. The percentage yield can be determined by calculating the following formula (Nasional, 2008).

$$\text{Yield}=\frac{\text{Input}}{\text{Output}}\,100\% \quad (1)$$

Measurement of moisture content is carried out in accordance with the procedures of the National Standardization Agency concerning SNI Oil Quality Standard No. 7381: 2008 using the oven method.

$$\text{Water content} = \frac{\text{Initial material weight-Final material weight}}{\text{Initial material weight}}\times 100\% \quad (2)$$

3. RESULTS AND DISCUSSION

3.1. Biofermentor Description

The biofermentor used has dimensions of 60 cm × 72 cm × 68 cm, capable of accommodating a fermentation container measuring 40 cm × 40 cm × 30 cm. This biofermentor is equipped with two 150-Watt infrared lamps as a heat source, a stirrer with a 12 V DC motor to evenly distribute the temperature, a 6 mm thick glass container for coconut milk fermentation, and a control box for the fuzzy control and IoT system. The control system consists of an Arduino Uno as the control center, an LM35 temperature sensor, SSR (DC to AC for the infrared lamp) an LCD for offline monitoring, and a NodeMCU ESP8266 for IoT.

3.2. Initial system identification

Before the installation of fuzzy control, the gain in the system showed a temperature increase up to nearly 44°C, which is higher than the highest targeted setpoint of 40°C. The material used for this initial test was water. The system identification results can be seen in Figure 2.

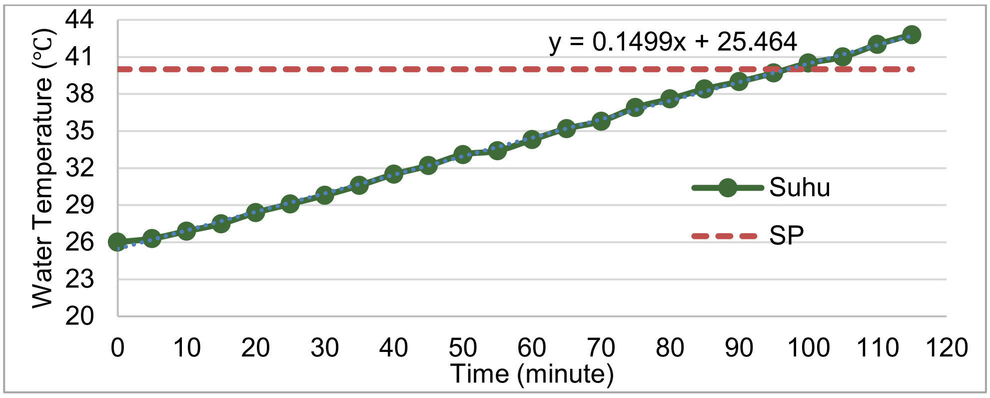

Figure 2. Water temperature during the gain test.

The gain value of the tool is 0.15 °C/minute, exceeding the setpoint temperature. This indicates that the 300-Watt infrared lamp used can raise the tool's temperature beyond the setpoint. However, continuous temperature increase may lead to fermentation failure. Therefore, a control system is necessary to stabilize the temperature. A fuzzy logic control system is ideal as it can increase the temperature without surpassing the setpoint, ensuring stable conditions. This aligns with the assertion that a fuzzy logic control system ensures process stability through its embedded rules (Nugroho, et al., 2022). Based on these results, the rules for the fuzzy logic control system were established. The following rules were created to control the biofermentor:

- R1. If (Error is en-0.1) and (Delta_Error is den-2) then (PWM is 0) (1)
- R2. If (Error is en-0.1) and (Delta_Error is dez0) then (PWM is 0) (1)
- R3. If (Error is en-0.1) and (Delta_Error is dep2) then (PWM is 10) (1)
- R4. If (Error is ez0) and (Delta_Error is den-2) then (PWM is 40) (1)
- R5. If (Error is ez0) and (Delta_Error is dez0) then (PWM is 100) (1)
- R6. If (Error is ez0) and (Delta_Error is dep2) then (PWM is 150) (1)
- R7. If (Error is ep4) and (Delta_Error is dep2) then (PWM is 255) (1)
- R8. If (Error is ep4) and (Delta_Error is dez0) then (PWM is 255) (1)
- R9. If (Error is ep4) and (Delta_Error is den-2) then (PWM is 255) (1)

Where R is rule, en is negative error, ez is zero error, ep is positive error, den is delta negative error, dez is delta zero error, and dep is delta positive error.

3.3. Fuzzy logic control

Based on the observations that have been made, as shown in figure 3, there is no spike in material temperature at the beginning of the process and the time required to reach the setting point temperature is 80 minutes. This settling time value is short compared to the fermentation process which lasted for 16 hours. This is in accordance with statement that a good system is a system that does not experience overshoot and short settling time (Ogata, 1995). So, the fuzzy logic control system applied to the biofermentor can be declared successful.

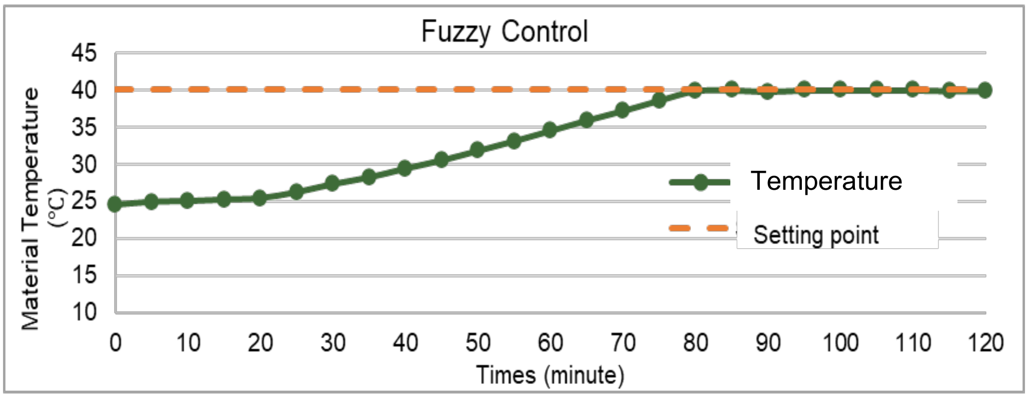

Figure 3. Dynamic response of system test with water

3.4. IoT Monitoring System

The ThingSpeak server used can receive and visualize biofermentor temperature and power data as long as the internet connection at the access point runs smoothly. The data transmission process is carried out within a 15 second delivery time frame. In addition, this ThingSpeak server can provide data in the form of excel files during the fermentation process and the data can be downloaded for free.

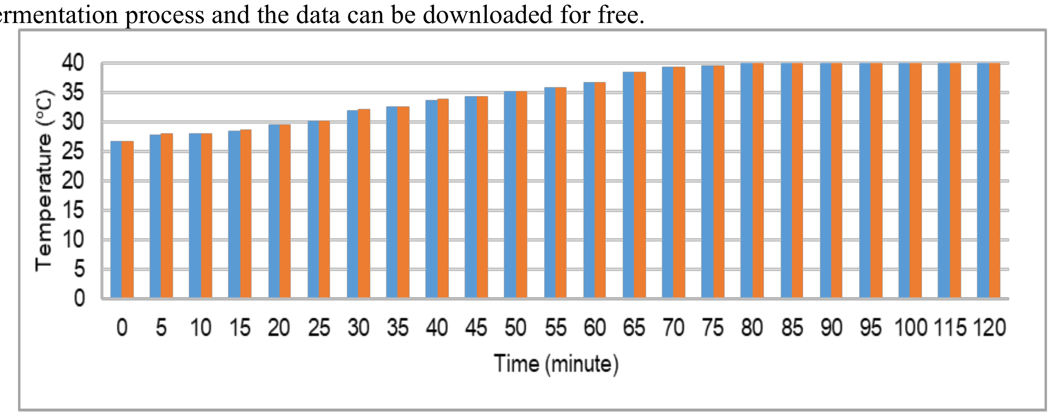

Figure 4. Temperature data comparation between ThingSpeak and displayed on LCD.

Temperature monitoring data is automatically sent to the ThingSpeak web server. The data transmitted via IoT shows results that are not significantly different from the real-time data recorded on the LCD, as shown in Figure 4. However, during the 17-hour data transmission testing process, a total of 3,624 data points were received, while 1,021 data points were lost, resulting in a data loss percentage of 22% of the total data that should have been transmitted. The internet used was a cellular provider network, which experienced instability at certain times, causing the internet connection to drop, coinciding with the data transmission period. As a result, delays occurred in the data transmission process. To address this, it is necessary to use a more stable internet connection, such as a fiber-optic cable network, or to modify the data transmission process in case of transmission failures. For example, by storing failed data and transmitting it in bulk once the connection is restored, data loss can be minimized. Nevertheless, delays or data loss do not affect the system's performance, as the transmitted data is only used for monitoring purposes, while the system control process operates independently through the microcontroller module. For further details on the data mapped every four hours, please refer to Table 1 below.

Table 1. Percentage of data sent, and data lost.

Times	Data sent	Data lost	% data lost
20:00 – 00:00 WITA	907	176	16%
00:00 – 04:00 WITA	904	367	29%
04:00 – 08:00 WITA	898	190	17%
08:00 – 12:00 WITA	914	288	24%

3.5. Performance test

3.5.1. Dynamic response

The application of fuzzy logic control system on the device occurred overshoot at 40 °C treatment of 0.3 °C or 1% but settling time more than 80 minutes (figure 6), meanwhile for 29 0C less than 15 minutes (figure 5). The difference in settling time value is influenced by the magnitude of the setting point temperature which is 11 °C adrift. Based on the data in Figures 5 and 6, the control system applied is good enough because there are no binding rules related to the magnitude of the overshoot value and settling time that is considered good, but if there is no overshoot and short settling time is the better (Ogata, 1995).

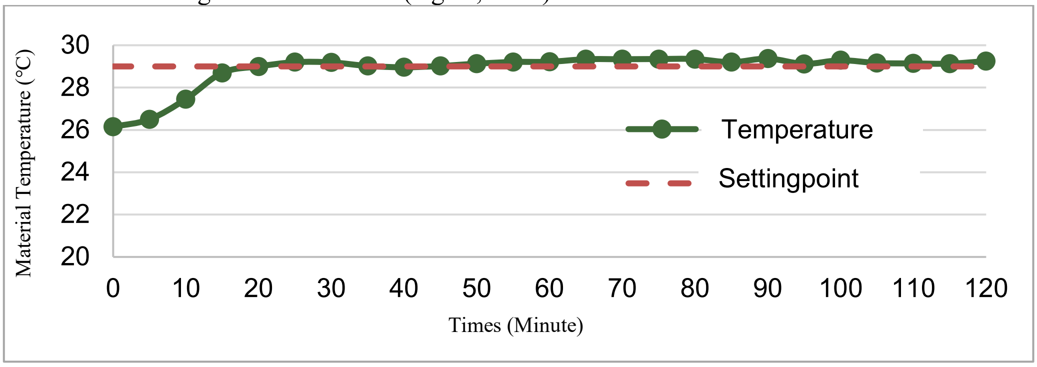

Figure 5. Dynamic response of settingpoint treatment 29 °C.

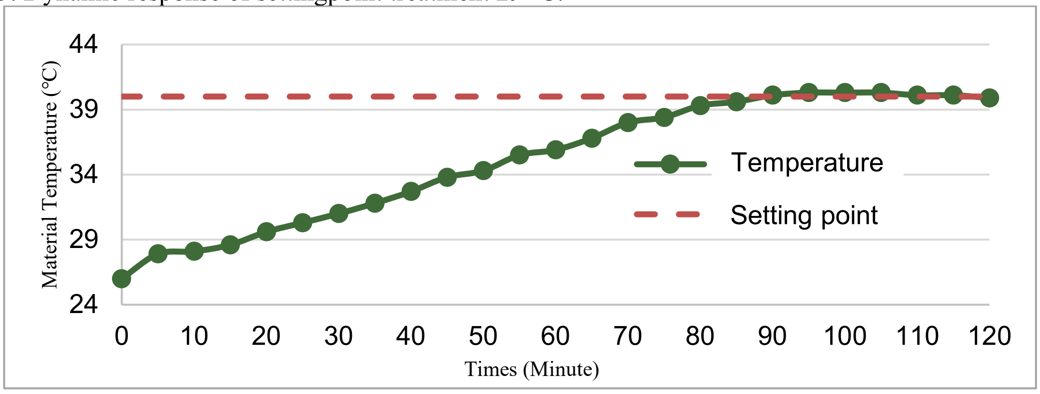

Figure 6. Dynamic response of settingpoint treatment 40 °C.

3.5.2. Steady state response

Steady state response analysis is carried out to show that the applied fuzzy logic control system is able to run the biofermentor with a stable temperature and has a steady state error value that is smaller than the predetermined tolerance value. Based on the logger data obtained from ThingSpeak in Figures 10 and 11, it can be seen that the application of the fuzzy logic control system applied to the biofermentor is able to make the temperature stable and the steady state error value that occurs in each setting point temperature treatment of 29 °C and 40 °C is 1.02% and 1% respectively, which means it is still below the tolerance limit. The limit value for steady state error is 2-5% (Ogata, 1995).

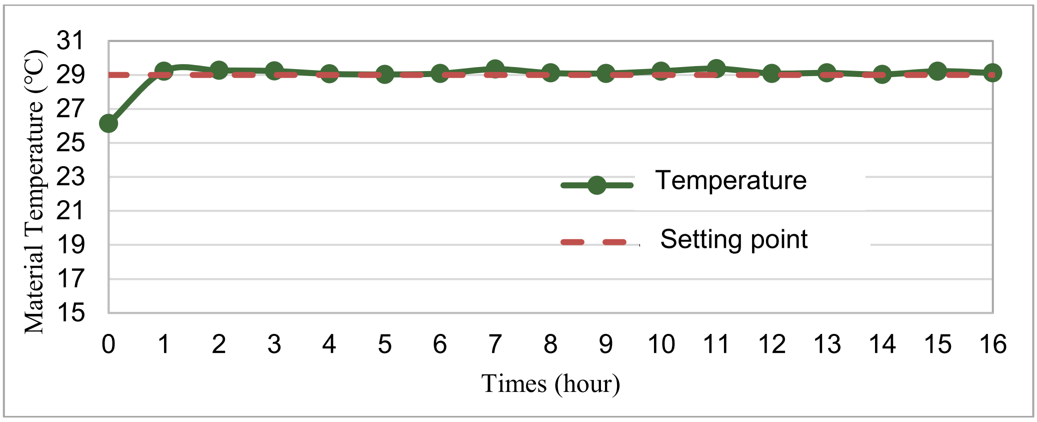

Figure 7. The steady state response of the setting point treatment material temperature is 29 °C.

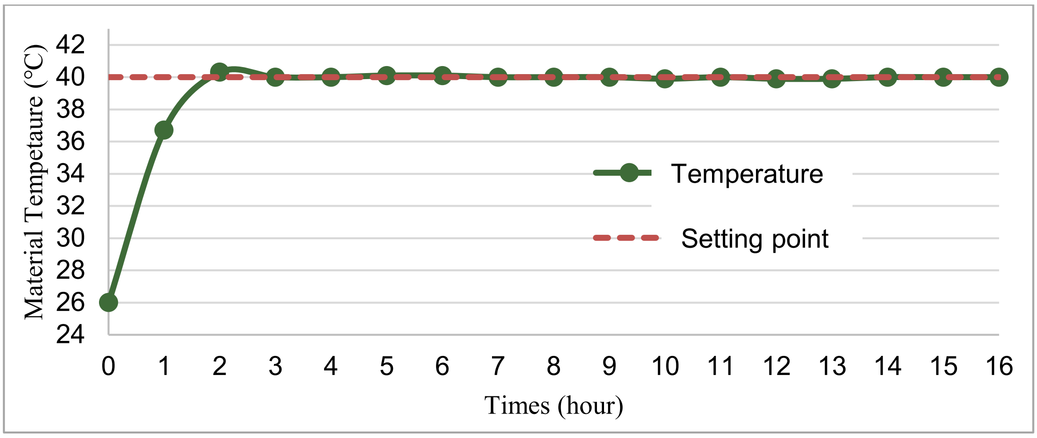

Figure 8. The steady state response of the setting point treatment material temperature is 40 °C.

3.6. Yields

The highest product yield was achieved using a biofermentor at temperatures of 29℃, 40℃, and 35℃, respectively. For comparison, previous research by (Wiranda, 2019) conducted conventional fermentation, which resulted in lower product yields at temperature variations of 24-27℃ and 26-28℃ (temperatures are given as ranges because they could not be precisely controlled). The average difference in yield between the two methods, biofermentor and conventional, was 7.21%, with the biofermentor method producing higher yields than the conventional method.

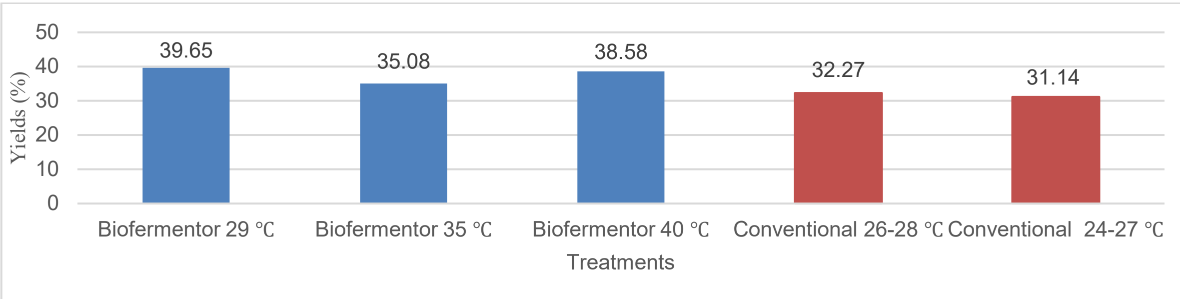

Figure 9. Yield of each treatment.

Based on Figure 9, the optimum temperature used in the VCO fermentation process is 29℃, yielding a higher product yield of 39.65% compared to the 35.08% yield obtained at 35℃. This result differs from the established statement that the optimum temperature for lipase from coconut is 35℃ under complete nutritional conditions (Ejedegba, et al., 2007). The discrepancy may be attributed to the inconsistency in the maturity level of the coconuts used as raw material for VCO production, leading to variations in the oil content of the coconuts. The oil content is significantly influenced by the fruit's maturity; the older the fruit, the higher the oil content (Ngatemin, et al., 2013).

Upon reviewing the data in Figure 9, it is evident that temperature stability significantly influences the success of the VCO fermentation process. Fluctuations in temperature can lead to fermentation failure. In the biofermentor treatment, a higher yield was achieved due to precise temperature control, ensuring a stable environment for optimal fermentation. Conversely, the conventional treatment resulted in a lower yield because it relied on uncontrolled ambient temperatures, leading to variations. This aligns with findings that highlight a key disadvantage of conventional methods: the inability to regulate material temperature, which destabilizes the fermentation process (Wiranda, 2019).

3.7. Water Content

Water content contained in VCO made using the biofermentor method was lower than using the conventional method. This indicates that the quality of VCO produced using biofermentor is better. The amount of water content of VCO using the biofermentor method from each treatment is suitable for consumption in accordance with the provisions of the Indonesian National Standardization Agency, which is a maximum of 0.2%. While the value of water content of VCO using conventional method is 0.28%. The difference in the value of water content between the two methods is influenced by the application and temperature uniformity of the materials used. In the conventional method, the temperature of the material is the same as the inadequate ambient temperature so that the temperature of the material is uneven, because the ambient temperature fluctuates around

25-29 °C. Whereas in the biofermentor method the temperature used is stable at the desired temperature and there is a stirrer to uniform the temperature of the material

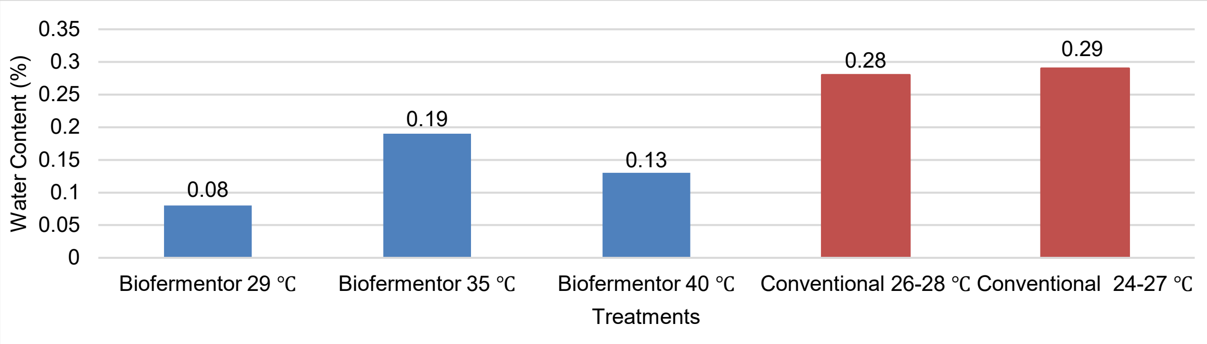

Figure 10. Moisture content value of each treatment.

4. CONCLUSION

Based on the research that has been done, it can be concluded that Fuzzy logic-controlled biofermentor successfully increases the volume without degrading performance characterized by good dynamic response (small overshoot, short settling time) and stable steady state response (steady state error value below the tolerance value of 2-5%). The water content value of VCO produced by biofermentor has met the SNI standard of 0.08%. The IoT system applied to the tool is visually helpful in monitoring and providing data during the fermentation process.

REFERENCES

Asmoro, W. N., Afriyanti, A., Widyastuti, R. & Ndrudu, J., 2018. Production of Virgin Coconut Oil Using. Volume 175, pp. 74 - 77.

Ejedegba, B. O., Onyeneke, O. C. & Oviasogie, P. O., 2007. Characterisitic of Lipase Isolated From Coconut (Cocos nucifera linn) seed under different nutrients treatments. *African Journal of Biotechnology,* 6(6), pp. 723-727.

Fadil, M., Munir, A. & Sapsal, M. T., 2023. On-Off Water Level Control and IoT Monitoring for Aquaponics Systems. *Salaga Journal,* 2(2), pp. 90-100. https://doi.org/10.70124/salaga.v1i2.1355

Nasional, B. S., 2008 . *SNI 731:2008 Minyak Kelapa Virgin (VCO).* Jakarta: Badan Standarisasi Nasional.

Ngatemin , N., Nurrahman , N. & Isworo, J. T., 2013. EFFECT OF FERMENTATION TIME ON VIRGIN COCONUT OIL (VCO) FORCHARACTER PHYSICAL, CHEMICAL, AND ORGANOLEPTIC. *Jurnal Pangan dan Gizi ,* 4(2), pp. 9-18.

Nugroho, A., Waris, A. & Muhidong, J., 2022. Application of Fuzzy Logic Control System in Fluidized Coffee Roaster. *Jurnal Agritechno,* 15(2), pp. 109-117.

Ogata, K., 1995. *Discrete Time Control Systems.* 2nd edition ed. New Jersey: Prentice Hall.

Wiranda, P., 2019. *(Skripsi) Kinerja Biofermentor Terkendali Fuzzy Logic dalam Proses Pembuatan Virgin Coconut Oil dengan Metode Enzimatis Papain (Carica papaya L.) ,* Makassar: Universitas Hasanuddin.

Zainul, R. et al., 2024. Comparative Analysis of Virgin Coconut Oil (VCO) Production Methods and their Impact on Nutritional and Chemical Properties. *Journal of Medicinal and Chemical Sciences,* pp. 2092-2107.