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SENSORY PREFERENCE DETERMINATION OF GREEN TEA EXTRACTS FROM UNCONTROLLED AND RELAY-CONTROLLED BREWING PROCESSES USING RANK ORDER CENTROID AND SIMPLE ADDITIVE WEIGHTING

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Abstrak

Ekstrak teh hijau merupakan produk minuman yang sangat populer karena berbagai manfaat kesehatannya. Sebagai upaya untuk meningkatkan daya tariknya di pasar, penting untuk memahami profil sensorik—seperti rasa, aroma, dan warna—agar produk ekstrak the hijau dapat diterima dengan baik oleh konsumen. Penelitian ini dilakukan untuk menemukan kondisi ekstraksi terbaik dengan menguji berbagai kombinasi waktu (3 atau 6 menit) dan suhu (60°C, 80°C, atau 100°C) dengan dua metode penyeduhan: (1) sistem penyeduhan yang dikendalikan relay menggunakan Arduino, dan (2) proses penyeduhan konvensional tanpa sistem kendali. Evaluasi sensorik dilakukan oleh 30 panelis yang tidak terlatih menggunakan skala hedonik 9-titik. Selanjutnya, metode pengambilan keputusan Rank Order Centroid (ROC) dan Simple Additive Weighting (SAW) digunakan untuk menentukan produk yang paling disukai berdasarkan pengujian organoleptik. Hasil menunjukkan bahwa sampel dengan suhu ekstraksi 80°C dan waktu 6 menit mendapatkan skor rasa tertinggi, sementara aroma dan warna terbaik ditemukan pada sampel dengan suhu ekstraksi 100°C dan waktu 3 menit. Secara keseluruhan, hasil pengambilan keputusan menggunakan kombinasi metode ROC dan SAW menunjukkan bahwa sampel dengan suhu ekstraksi 100°C dan waktu 3 menit adalah yang paling disukai oleh panelis.

Kata kunci : teh, relay, organoleptik, ROC, SAW

Abstract

Green tea extract is a popular beverage known for its health benefits. To increase its market appeal, understanding the sensory profiles—taste, aroma, and color—of green tea extract is essential to ensure customer satisfaction. In this study, experiments were conducted to determine the optimal extraction conditions by varying extraction times (3 or 6 minutes) and temperatures (60°C, 80°C, or 100°C) in two brewing methods: (1) a relay-controlled brewing system utilizing Arduino, and (2) a standard brewing process without automated control. Sensory evaluations were conducted by 30 untrained panelists using a 9-point hedonic scale. Decision-making methods, Rank Order Centroid (ROC) and Simple Additive Weighting (SAW), were then applied to identify the most preferred product. Results indicated that the highest taste score was achieved by the 80C-6min sample, while the best aroma and color scores were observed in the 100C-3min sample. Overall, the decision-making process using the combination of ROC and SAW methods concluded that the green tea extract from the 100C-3min sample was the most preferred by the panelists.

Key words : *tea, relay, organoleptic, ROC, SAW*

INTRODUCTION

Green tea (*Camellia sinensis* L.) is a herbal plant native to China, now widely cultivated in Southeast Asia as a raw material for the development of traditional medicines. Today, green tea is a popular beverage known for its polyphenol content, which provides various health benefits. The polyphenols in green tea are strong antioxidants that have been shown to prevent diseases such as heart disease, hypertension, and cancer. Moreover, the polyphenol content in green tea is higher than that in black and oolong teas due to minimal degradation during processing. Green tea leaves contain about 30-40% polyphenols, while black tea leaves only contain around 3-10%. In addition to polyphenols, tea leaves also contain caffeine, a powerful astringent that provides a stimulant effect [1][2].

The polyphenol content in green tea extract products can serve as a strong positioning strategy for brands marketing their green tea products due to its health benefits. However, many Indonesians still prefer black tea over green tea, likely due to the stronger bitter taste of green tea extract compared to black tea. As a result, the sensory profiles—taste, aroma, and color—of green tea extract products are important factors to consider in order to ensure consumer acceptance. Several factors influence the sensory qualities of green tea extract, including extraction time and temperature [3]. Therefore, it is essential to determine the optimal combination of extraction time and temperature to achieve the desired sensory profiles of green tea extract.

Several common methods for decision-making in multi-criteria problems are Rank Order Centroid (ROC) and Simple Additive Weighting (SAW). The ROC method is used for assigning weights based on the priority rank of each criterion, typically expressed as, "The 1st criterion is more important than the 2nd, the 2nd is more important than the 3rd," and so on [4]. The ROC method has previously been applied as a weighting tool in performance evaluation and decision-making research. For example, Mesran et al. [5] used ROC and Operational Competitiveness Rating Analysis (OCRA) to assess lecturer performance, while Panjaitan and Desnelita [6] applied ROC along with Additive Ratio Assessment (ARA). Additionally, Irwan et al. [7] combined ROC with TOPSIS to determine the best employee.

Furthermore, the criteria weights from the ROC method will be further processed for decision-making using Simple Additive Weighting (SAW). The basic concept of SAW is to calculate the weighted sum of the performance ratings for each alternative across all criteria. The alternative with the highest weighted sum is considered the most preferred [8]. SAW has previously been employed as a decision-making tool in various fields, such as food product evaluation. For instance, Utama and Baroto [9] applied SAW to analyze the boiling process of soybeans for tempe production, focusing on the organoleptic quality of the tempe. Similarly, Savitri et al. [10] used SAW to assist in selecting the best bread based on its sensory profiles and doneness.

Prior to this study, Lestari [11] combined ROC and SAW methods for decision-making in selecting potential credit customers. Additionally, Sihombing et al. [12] applied ROC and SAW to identify the most outstanding student in junior high school. Sudipa and Puspitayani [13] further investigated the sensitivity analysis in the implementation of AHP-SAW and ROC-SAW for decision-making in scholarship awards, concluding that ROC-SAW showed lower sensitivity than AHP-SAW. However, no prior research has implemented ROC and SAW for sensory evaluation purposes. Therefore, this study applies ROC and SAW to determine the preferred sensory profiles of green tea extract based on specific combinations of brewing temperature and time. A relay-controlled brewing system, managed by an Arduino-based microcontroller, was also used to maintain the brewing temperature at a predetermined setpoint.

RESEARCH METHOD

Development of a Relay-Controlled Brewing System Using an Arduino-Based Microcontroller

Metode A relay-controlled brewing system was developed using the following components: (1) Arduino UNO ATmega328P, (2) MAX6675 K-Type Thermocouple, (3) 5V Relay, (4) 16x2 I2C LCD, (5) Breadboard, and (6) Electric Kettle. The circuit design for the relay-controlled brewing process is shown in Figure 1. In this system, the MAX6675 K-Type thermocouple functions as a sensor to obtain the water temperature in the electric kettle. This temperature data is transmitted to the Arduino microcontroller, where it is received as digital data and processed by the program embedded in the microcontroller. The LCD displays the current temperature read by the system.

The breadboard is used to connect jumper wires to the ports in the modules, sensors, and Arduino microcontroller, creating the experimental circuit based on the design and ensuring the system functions properly. The relay controls AC power to the electric kettle, acting as a switch to turn the electric current on and off as required during the heating process.

The Arduino-based microcontroller for the relay-controlled brewing process operates using IF-ELSE logic as follows: (1) If the temperature is lower than or equal to the setpoint, the relay allows electricity to flow to the kettle, continuing the heating process. (2) Otherwise, if the temperature exceeds the setpoint, the relay cuts off the electricity to the kettle, stopping the heating process [14].

Table 1. Arduino Codes Embedded in The System

Line	Code
1	#include <max6675.h>
2	#include <LiquidCrystal_I2C.h>
3	const int RELAY = 8 ;
4	int thermoDO = 4;
5	int thermoCS = 5;
6	int thermoCLK = 6;
7	MAX6675 thermocouple(thermoCLK, thermoCS, thermoDO);
8	LiquidCrystal_I2C lcd(0x27, 16, 2);
9	void setup() {
10	pinMode(RELAY, OUTPUT);
11	lcd.begin();
12	Serial.begin(9600);
13	}
14	void loop(){
15	float temp = thermocouple.readCelsius();
16	float correctTemp = (temp+0.08)/1.001;
17	float setpoint = 60; //80, or 100 °Celcius
18	lcd.setCursor(0,0);
19	lcd.print("Temperatur: ");
20	lcd.setCursor(0,1);
21	lcd.print(correctTemp);
22	if(correctTemp<=setpoint){
23	digitalWrite(RELAY,HIGH);
24	} else {
25	digitalWrite(RELAY, LOW);
26	}
27	Serial.println(correctTemp);
28	delay(500);
29	}

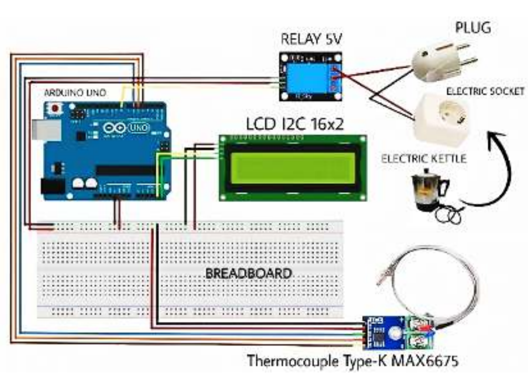

Figure 1. Circuit Design of Relay-based Temperature Control System using Arduino

Before being used in the relay-controlled brewing system, the MAX6675 K-Type thermocouple was calibrated using a post-calibrated EMCLAB DMSH-20D hotplate thermocouple. The calibration method was adapted from Riantono et al. [15] with slight modifications. Calibration was conducted using the linear regression method at five temperature points: 20, 40, 60, 80, and 100°C. The regression results are shown in Figure 2.

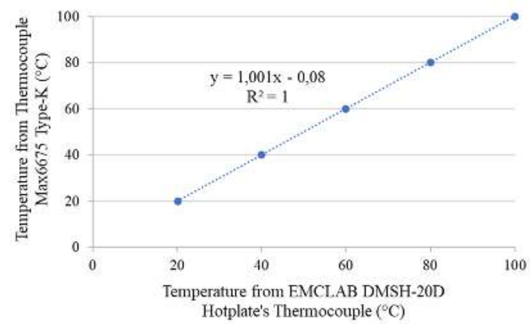

Figure 2. Linear Regression Between The Temperature Obtained from Thermocouple MAX6675 Type-K and EMCLAB DMSH-20D Hotplate's Thermocouple

The equation obtained by linear regression is $y = 1.001x - 0.08$. Thus, the inverse of the equation will be $y' = (x+0.08)/1.001$, which will be further used in the Arduino code to correct the temperature readings from the MAX6675 K-Type thermocouple. The complete Arduino code used in this study and embedded into the relay-controlled brewing system is presented in Table 1.

Green Tea Brewing Process Using Variations in Time and Temperature

A fixed amount of drinking water was heated in the electric kettle until it reached temperatures of 60°C, 80°C, or 100°C. To achieve temperatures of 60°C or 80°C, a relay-controlled brewing system was implemented using Arduino along with its modules and sensors. For heating to 100°C, the electric kettle was directly connected to the power supply without the control system, allowing the water to reach its boiling point (100°C). Once the water reached the target temperature, a commercial green tea bag was steeped in the heated water for 3 and 6 minutes. After the brewing process, the tea bag was removed, leaving the green tea extract in the kettle. The resulting extract was then stored in bottles for further sensory evaluation. Codes for each sample are presented in Table 2:

Table 2. The Codes of The Samples

Brewing Temperature (°C)	Brewing Time (minutes)	
	3	6
60	60C-3min	60C-6min
80	80C-3min	80C-6min
100	100C-3min	100C-6min

Sensory Evaluation of Green Tea Extracts

A sensory evaluation was conducted with 15 untrained panelists to assess the taste, aroma, and color of green tea extracts produced using the previously described methods. The assessments were carried out using a 9-point hedonic scale, with detailed scoring criteria presented in Table 3. The final scores for each product's taste, aroma, and color were then analyzed using descriptive statistics.

Table 3. The 9-point Hedonic Scale

Score	Grade
1	Dislike extremely
2	Dislike very much
3	Dislike moderately
4	Dislike slightly
5	Neither like nor dislike (neutral)
6	Like slightly
7	Like moderately
8	Like very much
9	Like extremely

Decision-Making on Sensory Preferences using ROC and SAW

The selection of the optimal green tea brewing process to achieve the highest preference for green tea extracts, based on sensory scores, was performed using Rank Order Centroid (ROC) and Simple Additive Weighting (SAW) as decision-making tools. The decision-making process begins with determining the weights for sensory evaluation criteria using the ROC method. The ROC formula is presented as follows [6]:

$$Wk = \frac{1}{k}\sum_{i=1}^{k}\left(\frac{1}{i}\right) \qquad (1)$$

where Wk is the final weight of each criterion, k is the number of criteria, and i is the priority level of each criterion, which is prior determined by assigning the priority order. In this study, the priority order of each criterion was obtained using an interview with an expert in the field of agro-industrial engineering. Further, the weight of each criterion along with the sensory evaluation scores of the alternatives are processed by SAW by the following procedures: [16]

1) Determining the criteria (Cj) and alternatives (Ai) used in decision-making, where i is the number of rows (i = 1, 2, ..., n) and j is the number of columns (j = 1, 2, ..., m).
2) Filling in the performance ratings for each alternative on all criteria. The performance ratings were obtained from the mean calculation of organoleptic scores.
3) Determining the weight values (W) for all criteria. The weight value for each criterion is obtained from the calculation of the Rank Order Centroid (ROC).
4) Creating a decision matrix (X) using the values of performance ratings for each alternative on all criteria. Thus, the configuration of the decision matrix will be as follows:

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1j} \\ \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} \end{bmatrix} \qquad (2)$$

5) Normalizing the decision matrix by calculating the normalized performance ratings (r_{ij}) depending on the attribute type: (1) benefit, or (2) cost. The equation for each type will be as follows:

$$r_{ij} = \begin{cases} \dfrac{x_{ij}}{\max_{x_{ij}}} & \text{if j is a benefit attribute} \\ \dfrac{\min_{x_{ij}}}{x_{ij}} & \text{if j is a cost attribute} \end{cases} \qquad (3)$$

6) Performing the weight sum calculation to determine the final preference score (Vi) for all alternatives using the equation of:

$$Vi = \sum_{j=1}^{n} W_j\, r_{ij} \qquad (4)$$

The alternative that has the highest V_i score will be chosen as the final result of the decision-making process, which also indicates its position as the best alternative for the brewing process to produce the most preferred green tea extract based on its sensory scores.

RESULT AND DISCUSSION

The Analysis of Water Heating Profile

The circuit design implementation of the system of relay-controlled brewing process using Arduino is presented in Figure 2. The water heating profile obtained from both experiments: (1) the electric kettle with a system of relay-controlled brewing process, and (2) the electric kettle without implementing the control system, can be seen in Figure 3. The rise time required by the relay-controlled brewing process system to achieve temperature setpoints of 60°C and 80°C is 166 seconds and 228 seconds, respectively. Furthermore, overshoot occurred in the responses at both setpoints. The overshoot values were 20.17% and 18.54% for the temperature setpoints of 60°C and 80°C, respectively.

The overshoot in both systems occurred due to the preserved heat in the heating element of the electric kettle, even though the electric current had been shut off by the relay. As a result, the heat was transferred to the systems, causing the temperature to rise above the predetermined setpoints. Furthermore, the heating process without the control system showed that the temperature in the kettle continuously increased until it stabilized at 100°C. The heating process did not further increase the temperature because the boiling point of the water had been reached. The heat supplied to the system was used by the water as latent heat to convert the phase of the water from liquid to vapor [14].

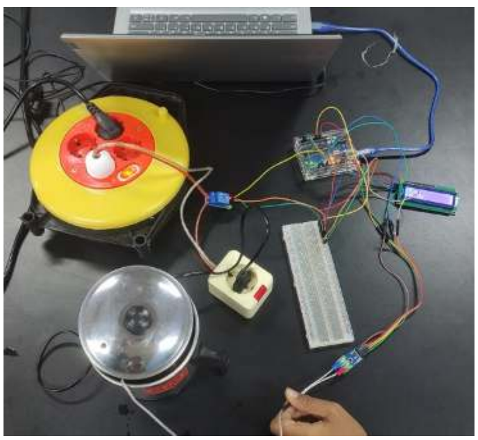

Figure 2. Circuit Design Implementation of The System of Relay-Controlled Brewing Process using Arduino

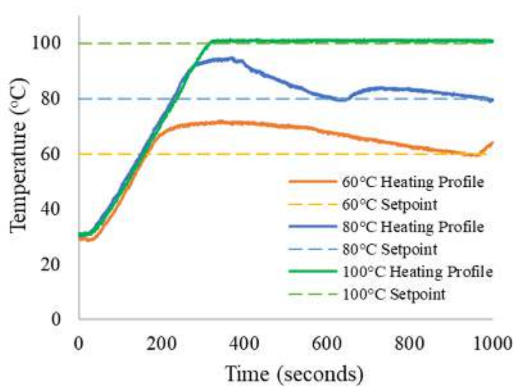

Figure 3. Water Heating Profile in Electric Kettle

The Analysis of Sensory Evaluation

The samples of green tea extracts produced are presented in Figure 4, which consists of the samples: (A) 60C-3min, (B) 80C-3min, (C) 100C-3min, (D) 60C-6min, (E) 80C-6min, and (F) 100C-6min, from left to right, respectively. The results of the sensory evaluation are presented in Table 4. The highest score for the criterion of taste was obtained by the sample of 80C-6min. Meanwhile, the highest scores for the criterion of aroma and color were obtained by the sample of 100C-3min.

The results showed that the combination of extraction time and temperature affected the taste of the green tea extract. Higher extraction temperatures increased the taste score of the green tea extract, likely due to the higher solubility and diffusion of green tea components into the water [17], except for the sample of 100C-6min. The lower score obtained by the sample of 100C-6min is likely due to the over-extraction of green tea components, which caused the taste to become more astringent and bitter. The astringent and bitter taste of the tea is attributed to the presence of caffeine, tannin, and catechins.

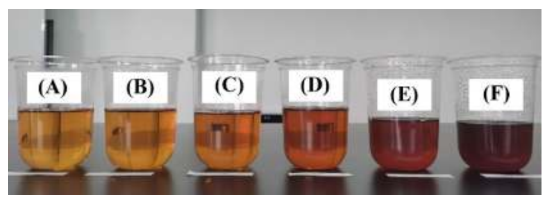

Figure 4. Green Tea Extract Produced by Various Brewing Times and Temperatures

The higher extraction temperature also increased the overall scores for the aroma of the green tea extracts. This is likely due to the higher concentration of green tea components extracted into the water [18], which affects the aroma of the green tea extract produced. However, in this study, the panelists' preferences leaned more towards the 100C-3min sample compared to the 100C-6min sample.

Table 4. Sensory Evaluation Results

Alternatives	The Average Score of Sensory Evaluation		
	Taste	Aroma	Color
60C-3min	5.27±1.39	5.33±0.82	6.07±1.28
80C-3min	6.20±1.01	6.00±1.20	7.13±1.13
100C-3min	6.60±1.84	7.87±1.06	7.53±0.64
60C-6min	6.27±1.10	6.27±1.22	6.67±1.40
80C-6min	6.87±1.06	7.07±1.10	7.27±1.10
100C-6min	6.07±2.69	7.40±1.45	5.87±1.51

The higher extraction temperature and longer extraction time also affected the panelists' preference for the color of the green tea extracts. The scores varied for all alternatives, but the sample of 100C-6min had the lowest color score. This result is likely due to the over-extraction of green tea components, caused by the longest extraction time and highest extraction temperature, which led to a significant increase in color intensity. As a result, the color of the green tea extract of 100C-6min was the darkest compared to the other alternatives. Furthermore, the color intensity is also affected by the conversion of tannin into theaflavin and thearubigin [19]. The excess evaporation of water due to longer heating times at the boiling point also contributed to the increase in color intensity of the product.

Decision-making on The Sensory Evaluation Results Using ROC and SAW

The sensory evaluation results presented in the previous sub-chapter show different scores for the taste, aroma, and color of green tea extracts across all alternatives. Therefore, decision-making methods were implemented to obtain the final decision on the most preferred green tea extract. In this study, Rank Order Centroid (ROC) was implemented as the weighting method for the criteria, while Simple Additive Weighting (SAW) was used as the decision-making tool for the alternatives.

Table 5. The Weight Calculation of Criteria by ROC

Criterion	Weight Calculation by ROC
Taste	$\frac{1+\frac{1}{2}+\frac{1}{3}}{3} = 0.611$
Aroma	$\frac{0+\frac{1}{2}+\frac{1}{3}}{3} = 0.278$
Color	$\frac{0+0+\frac{1}{3}}{3} = 0.111$

The first step of the decision-making process was carried out by determining the weight of the criteria of taste, aroma, and color using ROC, which describes their priority rank. In this study, the priority rank of the criteria was obtained through the interview with an expert in the field of agro-industrial engineering. The final conclusion for the priority rank of the criteria is Taste > Aroma > Color. Thus, the calculations of the weight of each criterion are presented in Table 5.

The next step was creating a normalized decision matrix from the data of sensory evaluation results in Table 4. The values of max xij for the criteria of taste, aroma, and color are 6.87, 7.87, and 7.53, respectively. Thus, the calculations were performed based on equation (3), and the result of the normalized decision matrix is presented in Table 6.

Table 6. Normalized Desicion Matrix

Alternatives	Normalized Value of Criterion		
	Taste	Aroma	Color
60C-3min	0.77	0.68	0.81
80C-3min	0.90	0.76	0.95
100C-3min	0.96	1.00	1.00
60C-6min	0.91	0.80	0.88
80C-6min	1.00	0.90	0.96
100C-6min	0.88	0.94	0.78

The normalized decision matrix is further processed for the calculation of the preference score for each alternative using equation (4). The results of the calculation are presented in Table 7. The sample of 100C-3min obtained the highest preference score (Vi) with a value of 0.976. This is due to (1) the highest scores for aroma and color and (2) an excellent score for taste obtained by the sample of 100C-3min compared to the other alternatives.

Although the taste score obtained by the sample of 80C-6min is higher than that of the sample of 100C-3min, the difference is quite small and does not significantly affect the final result of the preference score.

Table 7. Final Preference Score (Vi) Calculation for Alternatives

Alternatives	Normalized Value and Weight of Criterion			Final Preference Score (Vi)
	Taste 0.611	Aroma 0.278	Color 0.111	
60C-3min	0.77	0.68	0.81	0.746
80C-3min	0.90	0.76	0.95	0.869
100C-3min	**0.96**	**1.00**	**1.00**	**0.976**
60C-6min	0.91	0.80	0.88	0.877
80C-6min	1.00	0.90	0.96	0.968
100C-6min	0.88	0.94	0.78	0.888

CONCLUSION

Green tea extracts were successfully produced by (1) a system of relay-controlled brewing process and (2) a brewing process without implementing the control system. The results of the sensory evaluation showed that the highest score for the criterion of taste was obtained by the sample of 80C-6min, while the highest scores for the criterion of aroma and color were obtained by the sample of 100C-3min. The decision-making process using ROC and SAW concluded that the most preferred green tea extract was obtained by the sample of 100C-3min. However, it should be noted that the results of future studies may vary due to differences in the source of the green tea and the equipment used. Further studies should also examine the effect of the control system on the physicochemical properties of the product and its involvement in the decision-making process.

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