Performance Analysis of MOS Sensors on Electronic Nose for Synthetic Flavor Classification

Radi[1,*] Barokah[1] Luthfi Fadillah Zamzami[1] Andi Setiawan[1]

[1]*Department of Agricultural and Biosystems Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada, Yogyakarta, Indonesia*
[*]*Corresponding author. Email:* radi-tep@ugm.ac.id

ABSTRACT
An electronic nose is a device designed to sense, classify, and recognize a product based on its aroma. The electronic nose is generally designed from four main parts, namely: sample handling and delivery system, detector system, signal conditioning and preprocessing, and pattern recognition software. The detector section is a series of gas sensors that have different levels of gas sensitivity and selectivity. The sensor used in the electronic nose sometimes has low sensitivity, resulting in the undetected material being tested. Therefore, the electronic nose requires a selected sensor to optimally detect certain scents. The purpose of this study was to analyze the performance of the MOS sensor on an electronic nose for synthetic flavor classification. The types of gas sensors used in the electronic nose design are MQ 2, MQ 3, MQ 4, MQ 5, MQ 6, MQ 7, MQ 8, and MQ 9. The test sample used is liquid synthetic flavors with two different aroma variants (jackfruit and pandan). The gas sensor response analysis consists of two stages, namely pre-treatment data processing and pattern classification based on the principal component analysis method. The results of PCA show that the MQ sensor can classify the two samples well. The total variance of PC 1 and PC 2 for the MQ sensor-based electronic nose is 96,36%.

Keywords: *MQ sensor, TGS sensor, Electronic nose, Synthetic flavor, Pattern recognition*

1. INTRODUCTION

Consumer acceptance of a food product is generally based on appearance, texture, aroma, and taste. Aroma is one of the important parameters that determine the quality of a food product, such as food and beverage that have a fruity aroma. Food or beverage often experience a decrease in aroma quality after being processed and preserved, thus requiring food additives to maintain and strengthen the aroma. Synthetic flavors are one option to solve this problem. Synthetic flavors are food additives that provide or strengthen the taste and aroma of food products. The choice of using this flavor is because it is more practical in its application and is more economical, and the variants of synthetic flavors on the market are very diverse. The use of synthetic flavors has received serious attention from the industry [1]. The development of various more innovative flavors is carried out to meet the needs of consumers. Aroma is one of the important aspects for the flavor industry to maintain product quality [2]. One technology that allows for the analysis of synthetic flavor is the electronic nose [3].

An electronic nose is a low-cost digital electronic device that mimics the human olfactory system [4], [5]. In the human olfactory system, the aroma of a natural sample is arrested by the receptor and then processed by the brain to recognize the aroma obtained, while the electronic nose receptor system is replaced by an array of gas sensors then the gas sensor response will be processed in a signal conditioning system and pattern recognition [6]. The electronic nose consists of 3 main parts, namely the sample handling system, the detection unit, and the pattern recognition unit [7], [8]. The detection unit consists of a series of gas sensors with partial specifications [9]. The gas sensor circuit has an important role in the electronic nose to detect an aroma [10].

The working principle of the electronic nose is based on the identification of volatile organic compounds (VOC) produced by the sample in the form of output in the form of a voltage difference detected by a series of gas sensors [11]. The VOC that composes a material consists of 100-900 volatile components; so the gas sensor used by the electronic nose circuit must be

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adjusted to the type of aroma to be detected [3]. Selecting a selective sensor can improve the performance of the electronic nose in detecting aroma.

The gas sensor that is often used in the electronic nose is a Metal Oxide Semiconductor (MOS) gas sensor [12]. This sensor is in great demand because of its relatively easy use [13]. The MOS sensor has relatively low sensitivity, whereas the new sensor can detect the presence of a substance when the substance has a concentration of several parts per million (ppm). The MOS sensor is composed of n-type semiconductor materials such as SnO_2, ZnO, Fe_2O_3, and WO_3 [14]. This type of sensor produces a response in the form of a change in conductivity when interacting with reducing gases such as H_2, CH_4, CO, C_2H_5, or H_2S. The sensor operates well at a temperature of 200-500ºC. The most widely used semiconductor material as a gas sensor is SnO2 which is given a small number of additional impurities and catalytic metals. MOS sensors generally have relatively poor selectivity; but are responsive to a wide variety of gases, such as flammable gases [15]. The mechanism for changing the conductivity of the MOS sensor when interacting with the reducing gas is described in Equations 1 and 2.

$$e + \frac{1}{2} O_2 \rightarrow O_{(s)}^{-} \quad (1)$$

$$R_{(g)} + O_{(s)}^{-} \rightarrow RO_{(g)} + e \quad (2)$$

where e is the free electron from the conduction band of the semiconductor material, R(g) is the reducing gas, and s represents the 'surface' which indicates the location of the reactants and products on the surface of the material and g represents the 'gas' which indicates the phase of the reactants and products. On the surface of the MOS sensor semiconductor material, there is physiochemical adsorption of several oxygen atoms from the environment to capture free electrons on the surface of the material as described in equation 1. This process produces a highly resistive barrier layer around the surface of the material. The presence of such a barrier limits the electron flow and causes a decrease in the conductivity of the sensor. When there is exposure to a reducing gas, the surface of the semiconductor material absorbs the gas molecules and causes an oxidation process as described in equation 2. This process lowers the resistance of the barrier layer and allows electrons to flow more easily, in other words increasing the conductivity of the sensor [16].

The types of MOS sensors that are often applied to the electronic nose are the MQ sensor and the TGS sensor. MQ sensors have many types and different sensitivities. The characteristics of the MQ sensor can change its conductivity along with changes in the concentration of the surrounding gas. In general, the MQ sensor has two main parts, namely the SnO_2 sensor which is connected to the H pin, and the heater which is connected to the H pin to heat the sensor material. The stability of the heater is influenced by the stability of the power supply. The TGS sensor or Taguchi Gas Sensor is a sensor manufactured by Figaro Engineering Inc. TGS consists of two main parts, namely the SnO_2 sensor and heater. The TGS sensor has a resistance change based on the concentration of the gas under study. The higher the gas concentration, the lower the resistance [17]. The heater on the TSG functions to clean the sensor room from outside air contamination.

Research related to electronic nose applications based on MQ sensors and TGS sensors for the identification of synthetic flavors is still very limited. In 2021, [18] used an electronic nose to classify synthetic flavors, but very little information has been obtained regarding the gas sensor used in the electronic nose series, which is the type of gas sensor. Therefore, the purpose of this study was to compare the performance of the MQ and TGS gas sensors on the electronic nose for the classification of synthetic flavors.

2. METHOD

2.1. Hardware of Electronic Nose

The hardware used in this research is an electronic nose design based on a series of gas sensors equipped with a controlled sample handling system and integrated with airflow recovery. The electronic nose device is integrated with a recovery system which functions to speed up the recovery of the sensor after being used for sampling. The recovery system is designed with a combination of valves and purge gas supply lines that allow it to flow quickly. The developed electronic nose includes 4 main parts, namely sample handling and delivery system, detector system, signal conditioning and preprocessing, and pattern recognition software. The electronic nose hardware is shown in Figure 1.

The sample handling and delivery system consist of 6 sample chambers that use to place samples. This system uses a heater and fan to control the temperature of the sample chamber box so that it is stable during the data collection process. The delivery system uses oxygen as the carrier gas. The detector system consists of 8 MOS-type gas sensors, namely MQ 2, MQ 3, MQ 4, MQ 5, MQ 6, MQ 7, MQ 8, and MQ 9. The gas sensor has a sensitivity to certain gases. Table 1 shows the gas sensors and their sensitivities used in the electronic nose.

The signal conditioning and preprocessing section use an Arduino Mega 2560 microcontroller board with an ATMega 2560 microcontroller. The function of the microcontroller is as an analog to digital converter (ADC) with a resolution of 10 bits. The microcontroller functions to control all electronic nose components.

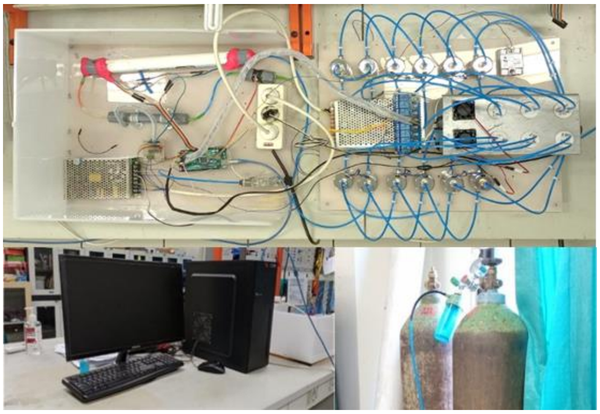

Figure 1 Hardware of electronic nose

Tabel 1 Details of sensor gas

Sensor	Gas sensitivity
MQ 2	Hydrogen, LPG, Methane, Carbon monoxide, Alcohol, Smoke and Propane
MQ 3	Alcohol, Benzene, Methane, Hexane, LPG and Carbon monoxide
MQ 4	LPG, Methane, Hydrogen and Alcohol
MQ 5	Hydrogen, LPG, Methane, Carbon monoxide and Alcohol
MQ 6	LPG, Hydrogen, Methane, Carbon Monoxide and Alcohol
MQ 7	Carbon monoxide
MQ 8	Hydrogen
MQ 9	Carbon monoxide and flammable gases

2.2. Sample Preparation

The synthetic flavor sample was measured as much as 5 ml. The sample is put into the prepared sample chamber. The sample chamber has been filled with the sample and then placed in the electronic nose sample chamber box. The form of synthetic flavor used for testing is in liquid form so that it evaporates easily, so it does not take time to produce headspace.

2.3. Procedure of Data Collection

The electronic nose is turned on then the data sampling process is carried out 1 time for 8 minutes without using a sample to stabilize the gas sensor array. During the data collection process, the O_2 airflow was set to remain stable at 0.4 L/min. Electronic nose performance test using a temperature setpoint of 40°C. The temperature setpoint is based on a preliminary test, which is looking for a temperature with a high gas sensor response signal but does not change the gas sensor response pattern [19].

A sampling of one sample chamber consists of flushing, collecting, and purging. Flushing is the result of reading the sensor response for 120 seconds without any test sample or airflow not passing through the sample chamber. Flushing is a reference value for sensor readings when exposed to clean air. The collecting process is a sensor response that is exposed to the aroma of the test sample for 180 seconds. In this process, the airflow will pass through the sample chamber. The purging process is re-cleaning the sensor chamber from exposure to the aroma of the sample for 180 seconds. The purging process airflow is the same as during the flushing process. The time required for the sampling process of one sample chamber is 480 seconds. Each synthetic flavor variant was tested in 30 replicates.

2.4. Data Analysis

The sample test data that has been obtained using a set of electronic noses are then processed using a computer. The data from the sample test results are in the form of ADC value data (bits) for the response of 13 gas sensors and will be stored in Microsoft Excel. Then the ADC value is converted into voltage units using the formula in Equation 3.

$$V = \frac{\text{Score x Reference voltage (5V)}}{1023} \quad (3)$$

Data analysis was carried out in 2 stages, namely pre-treatment of data processing and pattern recognition. Pre-treatment of data processing used is absolute data method. The purpose of pre-treatment is to extract the most important information from a data set from a single sample to reduce computational time and improve the analysis accuracy of pattern recognition systems. The classification of gas sensor response patterns from each synthetic flavoring variant used for analysis is the Principal Component Analysis (PCA) method. The PCA method used for analysis is the covariance method. The data processing uses the MATLAB R2016b application.

3. RESULTS AND DISCUSSION

3.1. Response of gas sensor

The results of the gas sensor responses are shown in Figures 2 to 5. The pattern of increase and decrease in the response of each gas sensor in each sample has different characteristics. The sensor response value to an aroma is influenced by several parameters including the intensity of the aroma component, and the selectivity and sensitivity of the sensor. Based on the picture, the gas sensor response begins to increase at 120 seconds, then tends to be flat and reaches a relatively stable state up to 300 seconds which is called the collecting process. The response of the MQ sensor is higher and the voltage value varies compared to the response of the TGS sensor. The MQ 8 sensor has the highest response value characteristic to the aroma of durian, jackfruit, and pandan flavors. MQ 8 sensor response reaches more than 700 on durian flavor. In the collecting process, the TGS sensor almost does not experience an increase in the value of the voltage, except for the TGS 2611 which has a response but is not too significant. The average TGS sensor voltage value is below 100.

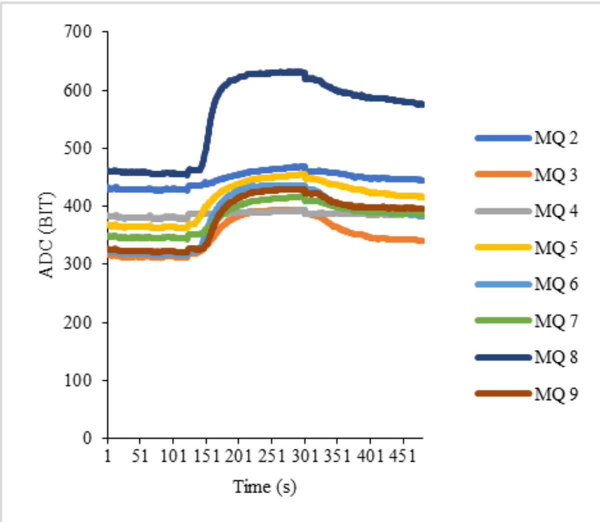

Figure 2 Gas sensor response to jackfruit flavor

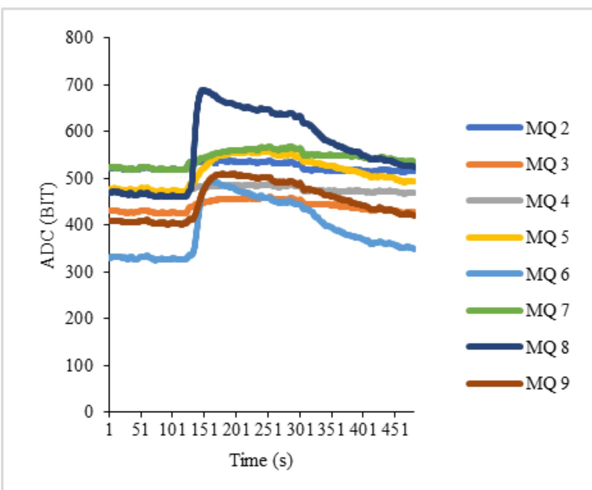

Figure 3 Gas sensor response to pandan flavor

The amount of data obtained from one sampling replication is 8 (the gas sensors) multiplied by 480 (sampling time) which is 3.480 data. Each flavor variant was sampled in 30 replicates. The big data will take a long time for the analysis process so a method is needed that can reduce the dimensions of the data to be easily recognized in the analysis of pattern recognition algorithms.

3.2. Pre-treatment Processing Data

The gas sensor response data that has been collected from the sampling process is still in the form of ADC (bits) so it needs to be converted into the form of voltage (V) using equation 3. The data is then simplified by taking the best value or pre-treatment data processing. Pre-treatment of data processing used is absolute data method. The absolute data method is done by taking the average data collecting, which is between the 291st second to the 300th second.

Pre-treatment of data processing was carried out on all data with 30 replications for each flavor variant. The data that has been pre-treated is then represented in the form of a radar graphic that resembles a spider's web. The radar graph serves to display data from 13 gas sensors and data for 30 replicates. Based on the graph, the results of the consistency and difference in the response values of each gas sensor will be obtained in responding to the aroma of each flavor variant.

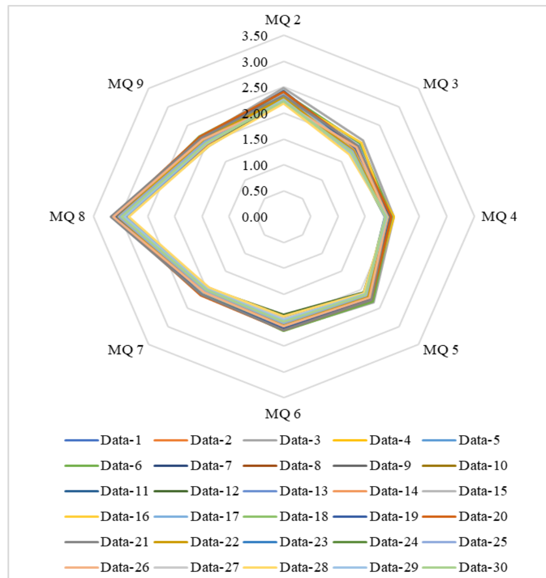

Figure 4 Sensor response pattern of jackfruit flavor

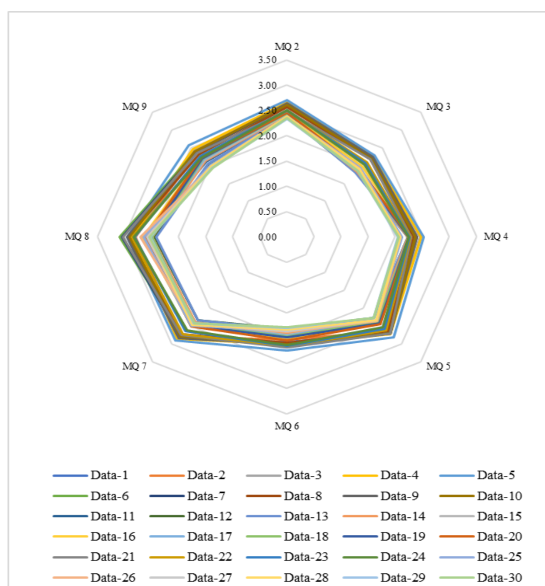

Figure 5 Sensor response pattern of pandan flavor

Figures 6 to 9 show the gas sensor response pattern for each synthetic flavor. Based on the picture, the MQ sensor has a different response pattern for each flavor variant, but the MQ sensor response has a fairly wide response value. Therefore, the MQ sensor was not consistent in responding to the synthetic flavor in each iteration, while the TGS sensor had a low response.

3.3. Result of PCA

Data that has been pre-treated with data processing and is represented using a radar graph is then processed using the PCA method. Data analysis using the PCA method aims to reduce the dimensions of the correlated variables into reduced variables that are not linearly correlated or called the principal components [20]. The number of input variables in the PCA process is 8 and 5 which represent the number of MQ and TGS sensors on the e-nose. One replication will be represented by one point on the PCA analysis score plot graph; so that each flavor variance will be represented by 30 points on the graph. The grouping of these points is based on the similarity of data, while different data will tend to spread or move away.

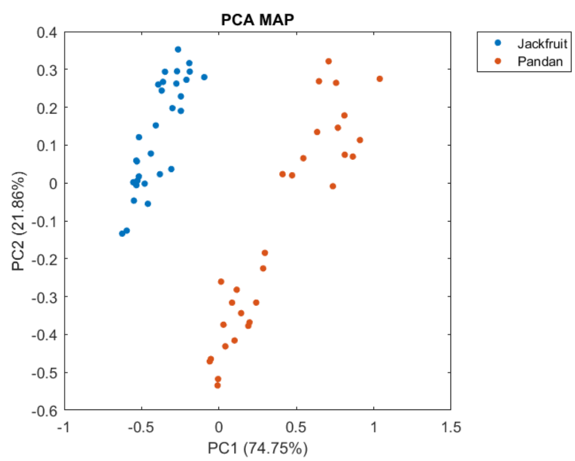

Figure 6 Score plot of PCA

Figure 8 shows the score plots for PC1 and PC2 based on the MQ sensor. The first two main components can explain the percentage of the variance of 74.75% for PC1 and 21.86% for PC2 of the total variance. The cumulative total of the first two main components is 96.36% which can represent a large part of the sensor response. Based on the figure, it can be seen that each variant is grouped and well separated. The cluster of jackfruit flavor is at coordinates PC1 [(-1) – 0] and PC 2 [(-0,2) – 0,4], while the cluster of pandan flavor is at coordinates PC1 [(-0,5) – 0,5] and PC2 [(-0,6) – 0,4]. The pandan flavor cluster is more spread out than the jackfruit flavor cluster. The cause of the resulting points spread out is the intensity of the gas sensor response that is not stable at 30 repetitions of data. The unstable gas sensor response is caused by the temperature in the sample chamber box, the temperature and humidity in the sensor room, the intensity of the sample aroma, and the unstable rate of the carrier gas.

4. CONCLUSION

The MOS sensor used for the classification of synthetic flavors can respond to aromas well, but these sensors cannot be stable for every data collection. The results of PCA show that the MQ sensor can classify the two samples well. The total variance of PC 1 and PC 2 for the MQ sensor-based electronic nose is 96,36%.

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REFERENCES

[1] K. Poornima and R. Preetha, Biosynthesis of Food Flavours and Fragrances - A Review, *Asian J. Chem.*, vol. 29, no. 11, 2017, pp. 2345–2352, doi: 10.14233/ajchem.2017.20748.

[2] R. Radi, E. Wahyudi, M. D. Adhityamurti, J. P. L. Y. Putro, B. Barokah, and D. N. Rohmah, Freshness assessment of tilapia fish in traditional market based on an electronic nose, *Bull. Electr. Eng. Inform.*, vol. 10, no. 5, 2021, pp. 2466–2476, Oct. doi: 10.11591/eei.v10i5.3111.

[3] A. J. Taylor and R. S. T. Linforth, Eds., *Food flavour technology*, 2nd ed. Chichester, U.K.; Ames, Iowa: Wiley-Blackwell, 2010.

[4] W. Jia, G. Liang, H. Tian, J. Sun, and C. Wan, Electronic Nose-Based Technique for Rapid Detection and Recognition of Moldy Apples, *Sensors*, vol. 19, no. 7, Mar. 2019, p. 1526, doi: 10.3390/s19071526.

[5] O. Kanoun, N. Derbel, and F. Derbel, Eds., Electronic Nose System and Principal Component Analysis Technique for Gases Identification, in *Sensors, Circuits & Instrumentation Systems*, De Gruyter Oldenbourg, 2018, pp. 167–180. doi: 10.1515/9783110448375-011.

[6] I. Tazi, N. L. Isnaini, M. Mutmainnah, and A. Ainur, Principal Component Analysis (PCA) Method for Classification of Beef and Pork Aroma Based on Electronic Nose, *Indones. J. Halal Res.*, vol. 1, no. 1, Feb. 2019, pp. 5–8, doi: 10.15575/ijhar.v1i1.4155.

[7] M. Roy and B. K. Yadav, Electronic nose for detection of food adulteration: a review, *J. Food Sci. Technol.*, Mar. 2021, doi: 10.1007/s13197-021-05057-w.

[8] S. Deshmukh, R. Bandyopadhyay, N. Bhattacharyya, R. A. Pandey, and A. Jana, Application of electronic nose for industrial odors

and gaseous emissions measurement and monitoring – An overview, *Talanta*, vol. 144, Nov. 2015, pp. 329–340, doi: 10.1016/j.talanta.2015.06.050.

[9] H. Liu, Q. Li, B. Yan, L. Zhang, and Y. Gu, Bionic Electronic Nose Based on MOS Sensors Array and Machine Learning Algorithms Used for Wine Properties Detection, *Sensors*, vol. 19, no. 1, Dec. 2018, p. 45, doi: 10.3390/s19010045.

[10] A. Wilson, Diverse Applications of Electronic-Nose Technologies in Agriculture and Forestry, *Sensors*, vol. 13, no. 2, Feb. 2013, pp. 2295–2348, doi: 10.3390/s130202295.

[11] P. Handa and B. Singh, Electronic nose and their application in food industries, *FOOD Sci. Res. J.*, vol. 7, no. 2, Oct. 2016, pp. 314–318, doi: 10.15740/HAS/FSRJ/7.2/314-318.

[12] Y. Cao, Y. Zhang, M. Lin, D. Wu, and K. Chen, Non-Destructive Detection of Damaged Strawberries after Impact Based on Analyzing Volatile Organic Compounds, *Sensors*, vol. 22, no. 2, Jan. 2022, p. 427, doi: 10.3390/s22020427.

[13] Y. Huang, I.-J. Doh, and E. Bae, Design and Validation of a Portable Machine Learning-Based Electronic Nose, *Sensors*, vol. 21, no. 11, Jun. 2021, p. 3923, doi: 10.3390/s21113923.

[14] X. Wu, J. Zhu, B. Wu, C. Zhao, J. Sun, and C. Dai, Discrimination of Chinese Liquors Based on Electronic Nose and Fuzzy Discriminant Principal Component Analysis, *Foods*, vol. 8, no. 1, Jan. 2019, p. 38, doi: 10.3390/foods8010038.

[15] D. Lelono, K. Triyana, S. Hartati, and J. E. Istiyanto, Classification of Indonesia black teas based on quality by using electronic nose and principal component analysis, New York, NY USA, 2016, p. 020003. doi: 10.1063/1.4958468.

[16] P. Wyszynski B J. K. ,. Elmore, J. S. ,. dan Methven, L. and Nakamoto T, *Flavour Development, Analysis and Perception in Food and Beverages*, 2015th ed. Cambridge, England ; Waltham, Massachusetts ; Kidlington, England : Woodhead Publishing. [Online]. Available: https://doi.org/10.1016/C2013-0-16460-4

[17] A. Faricha, S. Suwito, M. Rivai, M. A. Nanda, D. Purwanto, and R. A. R.P., Design of Electronic Nose System Using Gas Chromatography Principle and Surface Acoustic Wave Sensor, *TELKOMNIKA Telecommun. Comput. Electron. Control*, vol. 16, no. 4, Aug. 2018, p. 1457, doi: 10.12928/telkomnika.v16i4.7127.

[18] R. Radi, B. Barokah, D. N. Rohmah, E. Wahyudi, M. D. Adhityamurti, and J. P. L. Yuroto Putro, Implementation of an electronic nose for classification of synthetic flavors, *Bull. Electr. Eng. Inform.*, vol. 10, no. 3, Jun. 2021, pp. 1283–1290, doi: 10.11591/eei.v10i3.3018.

[19] D. Lelono, K. Triyana, S. Hartati, and J. E. Istiyanto, Development of Electronic Nose with Highly Stable Sample Heater to Classify Quality Levels of Local Black Tea, p. 7.

[20] S. Orzechowska, A. Mazurek, R. Świsłocka, and W. Lewandowski, Electronic Nose: Recent Developments in Gas Sensing and Molecular Mechanisms of Graphene Detection and Other Materials, *Materials*, vol. 13, no. 1, Dec. 2019, p. 80, doi: 10.3390/ma13010080.

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