Food Research 7 (2) : 280 - 288 (April 2023)
Journal homepage: https://www.myfoodresearch.com

FOOD RESEARCH

FULL PAPER

Apparatus development for detecting the freshness of chicken meat using TCS 3200, PH-98108, and MOS gas sensors

[1]Nastiti, P.W., [2,*]Bintoro, N., [2]Karyadi, J.N.W., [2]Rahayoe, S. and [2]Saputro, A.D.

[1]Doctoral Program of Department of Agricultural and Biosystems Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada, Jl. Flora No. 1, Bulaksumur, Yogyakarta 55281, Indonesia
[2]Department of Agricultural and Biosystems Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada, Jl. Flora No. 1, Bulaksumur, Yogyakarta 55281, Indonesia

Article history:
Received: 13 January 2022
Received in revised form: 16 February 2022
Accepted: 30 March 2022
Available Online: 18 April 2023

Keywords:
Chicken meat,
Quality,
Colour,
pH,
MOS gas sensors

DOI:
https://doi.org/10.26656/fr.2017.7(2).024

Abstract

Meat can be determined as a muscle that has entered a rigour mortis state. Due to its high nutritional content, the quality of chicken meat quickly decreased. The changes in meat colour, pH, and metabolite gas production, especially ammonia and hydrogen sulfide, are the typical indicators for meat degradation. This research aimed to design and build an apparatus to evaluate the freshness of the chicken meat displayed for sale or storage. In the following study, four different sensors, including TCS 3200 colour sensor, Metal Oxide Semiconductor (MOS) gas sensors (MQ 136, MQ 137), and PH-98108 sensors, were assembled with the aid of a microcontroller and personal computer to become a meat freshness detection apparatus. After being calibrated, the apparatus was then used to evaluate the freshness of the chicken meat sample. The results indicated that the apparatus showed satisfactory performance in detecting the freshness of the chicken meat sample. This apparatus was movable, simple, cheap, easy to operate, and suitable to be used by meat sellers or related institutions. The sensors used were capable of detecting the changes in colour, pH, NH_3 gas, and H_2S of the sample. The parameters of L*, b*, pH, H_2S, and NH_3 gas effectively detected the freshness of chicken meat. After 12 hrs of storage, the values of L*, b*, pH, H_2S, and NH_3 gas of the sample were 50.34, 17.26, 6.59, 134.08 ppm, and 42.34 ppm, respectively.

1. Introduction

Chicken breast meat contains a lot of protein, a vital macronutrient required by the human body. In Indonesia, the consumption of chicken meat per capita is 5.683 kg/ year, and this consumption increased by about 1.87% in 2018 (Kementan, 2020). This consumption is 12 times higher than beef per capita, 0.469 kg. Even though the consumption of chicken meat in Indonesia is high, the quality of the product is not well maintained. Chicken meat is mainly sold in traditional markets with minimal sanitation facilities and cooling systems. Due to this condition, physical and chemical damage quickly occurs. In addition, microbiological deterioration is also commonly found, leading to foodborne disease (Mead, 2004).

Organoleptic changes, including colour, odour, and pH, indicate the spoilage of chicken meat. The off-flavour becomes more intensive as the spoilage of the meat proceeds. Ammonia (NH_3) and hydrogen sulfide (H_2S) are used as spoilage metabolites because the degree of spoilage is related to the increase of those metabolites during storage (Li and Suslick, 2016). Metabolic processes and bacterial activity in utilizing free amino acids take a role in spoiling. Microbes synthesize unwanted compounds during metabolic processes, including biogenic amines, ammonia, CO, hydrogen sulfide, CO_2, and lactic acid (Shukla *et al*., 2015; Raudienė *et al*., 2018). The accumulation of lactic acid from the anaerobic glycolysis process causes the pH to decrease until the ultimate pH is reached. Colour pigment and its concentration generally influence the colour of meat. Time also affects metmyoglobin concentration, which increases with time and oxygen exposure (Hunt and King, 2012). Therefore, the more degraded the chicken meat, the more unpleasant the odour, pH decrease, and discolouration.

Monitoring chicken meat freshness is generally done by manually evaluating the smell, colour, and texture characteristics. Sensory evaluation is fast and easy, but it may lead to misinterpretation if the number and

*Corresponding author.
Email: *nursigit@ugm.ac.id*

eISSN: 2550-2166
Published by Rynnye Lyan Resources

speciality of the panellist are not enough. Chemical detection such as spectroscopy and chromatography is a better and standardized way of using standard analytical techniques (Kamruzzaman *et al*., 2012) but is time-consuming, requires a complex operation, skilled analyst, nonportable, and is expensive. Another method of evaluation by Near-Infrared Reflectance (NIR) to predict the quality attributes of chicken breast (Pectoralis major) has also been conducted. However, NIR is instrumentally and operationally quite expensive. The non-destructive analysis of the chemometric approach is widely used to classify meat products based on their chemical composition (Kamruzzaman *et al*., 2015). Other studies have described the use of chemometric models to predict the process of meat spoilage. Although these two methods are faster than chemical detection, they need pricey equipment. Therefore, it is important to develop practical tools so that butchers or other interested parties in the meat trade can quickly evaluate meat quality. Many sensors such as colour, gases, and acidity are available. Combining these sensors with the Arduino circuit is possible to develop a device that can evaluate chicken meat quality faster, easier, and cheaper. Therefore, this study aimed to design and create a device that can thoroughly investigate the quality and freshness of chicken meat.

2. Materials and methods

2.1 Materials

Materials needed to build the apparatus included a black acrylic board used to make the apparatus chamber, Arduino Uno as the sensor signal reader, Raspberry Pi used as the database storage, and HDMI LCD 7 inches used as the display monitor. The sensors installed were MQ 137, MQ 136, TCS3200, and PH-98108, used to sense NH_3, H_2S, colour (Red, Green, Blue), and pH. The other needed devices were Konica Minolta Chroma Meters CR-400, colour papers (Prima), Portable Multi-Gas Detector BH-4S for H_2S, and Ammonia Gas Detector AR-8500. Fresh chicken meat (Broiler), aged between 25-35 days, was used to test the apparatus. In the following research, chicken meat used was breast part, and this was purchased from the local market in Yogyakarta, Indonesia.

2.2 Chemicals and reagents

Distilled water and liquid ammonia were purchased from Progo Mulyo, Indonesia. The pH calibration used buffer solutions with pH 4, pH 7, and pH 9 (Hanna, Indonesia). The HCl-KCl buffer was prepared from 0.2 M KCl (Merck, Germany) and 0.2 M HCl (Merck, Germany) for a pH of 2.2.

2.3 Research methodology

2.3.1 Design and mechanism of the apparatus

Colour, gas and pH sensors were assembled and connected to Arduino and Raspberry Pi 3 circuits as the data acquisition system. Two types of sensitive gas sensors, namely MQ 136 and MQ 137, were used to measure ammonia and hydrogen sulfide as metabolites gases during meat decomposition. These sensors were mounted at the top of the chamber. During the test, these sensors were exposed to gaseous metabolites in the closed chamber of the apparatus. The colour sensor of TCS 3200 was placed directly on the chicken meat surface to assess colour changes. This colour sensor was equipped with four Light Emitting Diodes (LED) for the illumination requirement. At the same time, the PH-98108 as the pH sensor was placed perpendicular to the meat sample and slightly penetrated into the sample for measuring the pH value of the sample. The arrangement of the complete apparatus can be seen in Figure 1.

The measurements outputs of colour, gases, and pH were frequencies, resistance ratio, and voltage. The Raspberry Pi 3 was installed with a MySQL database to store the sensor reading data. These data were then exported to CSV form for further processing using Microsoft Excel. A calibration equation is used to convert the measured values to RGB, gas concentration (ppm), and pH values. Therefore, it was necessary to calibrate those sensors with standardized (calibrated) measuring equipment or materials before measuring the meat sample. Calibration was performed to ensure that the data read by the developed apparatus and standard calibrated tools were similar.

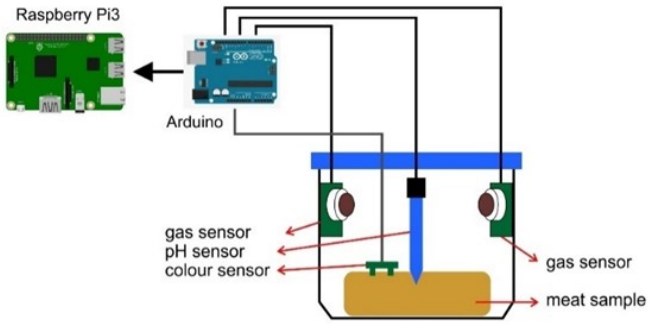


Figure 1. Schematic diagram of the developed apparatus

2.3.2 Colour sensor calibration

Detection of colour was carried out using the TCS3200 sensor in the apparatus, with the primary colours of the constituents being red, green, and blue (RGB). The colour calibration process was carried out by simultaneously measuring eight different colour papers using the developed apparatus and the calibrated colourimeter of Minolta Cr-400 Chromameter. The output reading from the developed apparatus in

https://doi.org/10.26656/fr.2017.7(2).024

frequency was then plotted against Minolta Cr-400 Chromameter readings to obtain the calibration graph and equation.

2.3.3 pH calibration

In the following study, calibration of the pH sensor (PH-98108) was done using standard buffer solutions. The sensor reading output of the apparatus was voltage. The standard buffer solutions (Hanna, Indonesia) consisted of HCL-KCL for pH values of 2.2, acetate buffer for pH 4.0, phosphate buffers for pH 7.0 and 9.0. Those prepared buffer solutions were directly measured using the apparatus and gave different voltage outputs for each buffer solution. Therefore, it could directly correlate between sensor reading in voltage and the known measured pH value. These data were then used to compile a calibration graph and find the pH calibration equation.

2.3.4 Gas sensors calibration

The output reading of the gas sensors was the resistance ratio (Rs/Ro). The Rs/Ro ratio is a reference to get the final result with ppm units (Sendari *et al*., 2019). Rs was the sensor resistances at different NH_3 and H_2S gases concentrations for MQ137 and MQ 136 sensors, respectively. While Ro was the resistance value of those sensors in clean ambient air. Several NH_3 and H_2S gas concentrations were prepared in a closed container from 0 – 100 ppm. Those gases were then measured using a standard calibrated device of Portable Multi-Gas Detector BH-4S for H_2S and Ammonia Gas Detector AR8500 for NH_3, where the measured values were expressed in ppm. At the same time, those gases (NH_3 and H_2S) were also measured using the developed apparatus, and the measured values were expressed in the Rs/Ro. The measurement data from the standard calibrated device (ppm) and the developed apparatus (Rs/Ro) were then plotted to obtain calibration equations.

2.3.5 Measurement method on chicken meat sample

After completing the calibration process, the apparatus was ready to measure the colour, pH, NH_3, and H_2S gases of a sample of chicken meat to determine its freshness. The chicken meat sample was loaded into the apparatus chamber and stored in ambient air of the tropical room condition at 29 - 30.5°C and relative humidity of 75 - 85%. Measurement was carried out periodically every hr during 24 hrs of storage. Measurement was done for three different samples of chicken meat (triplicate). The HDMI LCD 7 inch of the apparatus would display the sensor readings representing the colour attributes (R, G, B), NH_3 concentration, H_2S concentration, and pH of the sample.

2.3.6 Data analysis

The collected data from calibration measurements were analyzed by using regression analysis to determine the calibration equations. While for the chicken meat sample was analyzed by using a graphical and mathematical calculation to determine the changes in the meat quality attributes during storage.

3. Results and discussion

3.1 Colour sensor calibration results

As mentioned above, the colour sensor calibration was carried out by comparing the frequency with the colour recorded by chromameter Minolta CR 400 in R, G, and B values. Figure 2 shows the calibration results, the calibration equation, and the R^2 value. There was a linear relationship between those two readings, with the R^2 of R, G, and B being 0.9358, 0.9755, and 0.781, respectively.

Based on the results, B had the lowest R^2 value compared to the others, and this could be due to the blue colour exhibiting the shortest wavelength compared to red and green (Poynton, 2005). The wavelength of the light reflected from the object produces a colour perception that makes the light source influence colour production and perception. Different light sources, such as daylight, fluorescent, and tungsten filament lamps, gave different illuminant types (Hunt and King, 2012).

3.2 pH calibration result

Calibration of the pH sensor was performed by using buffer solutions with the known pH values at four levels

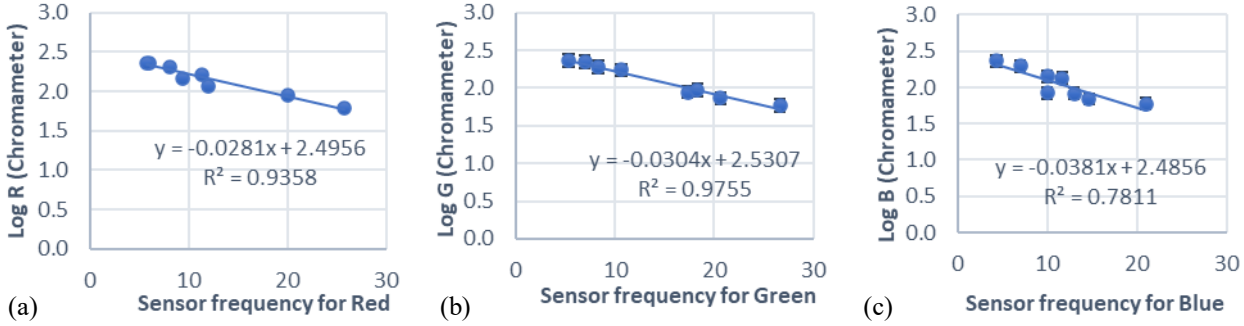


Figure 2. Calibration graphs of colour sensor (a) Red Value, (b) Green Value, and (c) Blue Value

https://doi.org/10.26656/fr.2017.7(2).024

of acidities. Figure 3 shows the calibration result of the apparatus. It could be found that there was also a linear relationship between sensor reading and the known pH of the buffer solutions with the R^2 value was 0.9998. Sari *et al.* (2016) also reported a linear relationship and studied the voltage level of couples buffer pH from five up to seven at room temperature. The same result was also found by Metrohm International Headquarters (1991). When the calibration method used the buffer solution, the accuracy of the conventionally measured pH value would increase significantly at higher ionic trends (Schneider *et al.*, 2004).

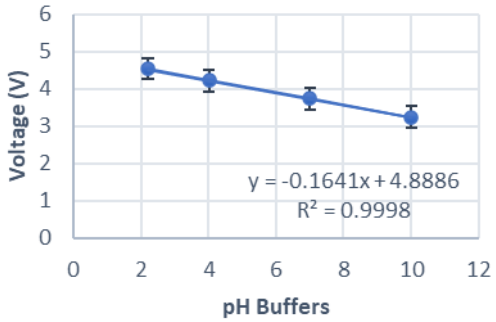


Figure 3. Calibration graph of pH sensor

3.3 Gas sensor calibration result

The two metal oxide semiconductor (MOS) gas sensors of both MQ 136 and MQ 137 used in the apparatus were calibrated based on the resistance ratio Rs/Ro (Qiu and Wang, 2017). This calibration method was based on the previous study that resulted in a logarithmic equation (Prasojo, 2017). MOS gas sensors are widely used in developing detection devices to monitor ammonia, hydrogen sulfide, and other volatile gases in the freshness test of chicken meat (Lee *et al.*, 2010). Another research on chicken spoilage by measuring NH_3 and CH levels using MOS gas sensors was conducted by Edita *et al.* (2018) and spoiled meat classification using MQ 136, MQ 137, and TGS 2602 gas sensors reported by Kartika *et al.* (2018). Detection of the type and concentration of adulteration in patchouli oil provides objective and reliable results using MOS gas sensors such as MQ 135 (Sudarmaji *et al.*, 2021).

Figure 4 shows the calibration result for the NH_3 gas sensor of the developed apparatus. MQ 137 sensor had a sensitivity to NH_3 gas (Ephipanias, 2018). When the sensor detects NH_3 gas, the sensor's conductivity increases as the gas concentration increases. As a result, the values of Rs/Ro decreased as the concentrations of NH_3 increased. The ratio Rs/Ro decreased as the NH_3 concentration increased was also reported by Lee *et al.* (2010). The relationship between sensor reading in Rs/Ro and log NH_3 concentration was linear, expressed as y = -0.9002x + 3.18 with an R^2 of 0.9908. This result indicated that the sensor could work properly and might give a good result in the actual application to detect the NH_3 concentration of the chicken meat sample.

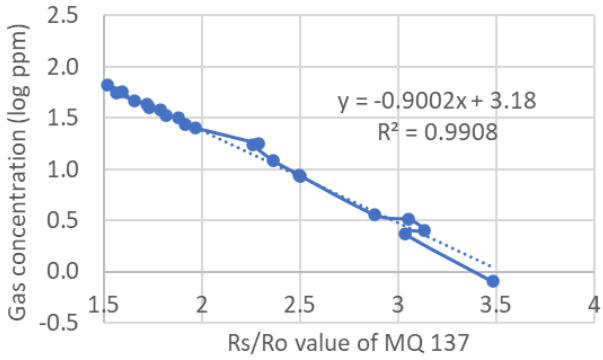


Figure 4. Calibration graph of NH_3 sensor

Figure 5 shows the calibration results for the H_2S sensor (MQ 136). The same as in the NH_3 gas sensor, the values of Rs/Ro decreased as the H_2S concentrations increased. The relationship between the sensor readings expressed as Rs/Ro and the log of H_2S concentrations formed a linear pattern which could be described as y = -1.3621x + 4.8843 with R^2 of 0.9746. As the MQ 137 sensor, this sensor could also work properly and might give a good result in the actual application to detect the H_2S concentration of the chicken meat sample. In another study conducted by Prasojo (2017), the measurement of H_2S in biogas purification using MQ 136 resulted in a satisfactory performance where the uncertainty value of the sensor was only about 2.77 at a 90% confidence level.

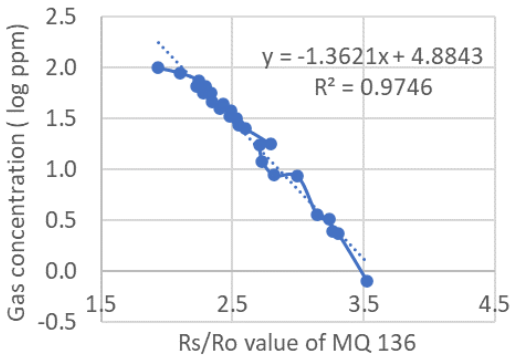
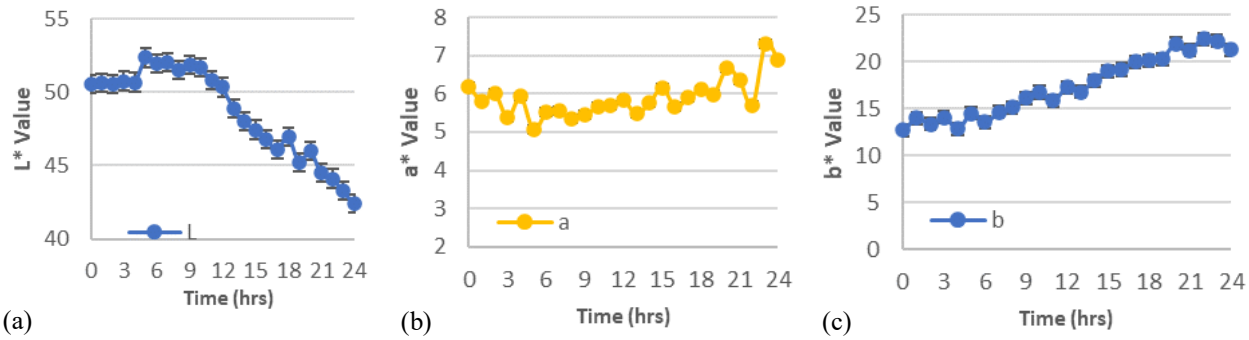


Figure 5. Calibration graph of H_2S sensor

3.4 Performance test on colour changes of the chicken meat sample

After being calibrated, the apparatus was then used to measure the changes in colour, pH, NH_3, and H_2S gases of the chicken meat sample. As stated above, in the current study, the reported parameter changes of the sample were investigated hrly during storage within 24 hrs at tropical ambient air temperature. There was a tendency for the meat colour sample to change a line with the increasing storage time. The colour changes of the chicken meat sample during storage are shown in Figure 6.

https://doi.org/10.26656/fr.2017.7(2).024



(a) (b) (c)

Figure 6. (a) L* values, (b) a* values, (c) b* values of the chicken meat during 24 hrs of storage measured by the device

The colour attributes were measured in R, G, and B and then converted to Lightness (L*), redness (a*), and yellowness (b*) values (Boronkay, 2013). The initial L* value of the chicken meat sample was 51, which was still in the normal range when referring to previous studies (Smith and Northcutt, 2009). In general, this value tended to decrease during 24 hrs of storage, from 51 to about 43 or decreased 15,7% or 0.653%/hr. As the L* value decreased, the meat tended to become darker, or the brightness of the chicken meat decreased. This phenomenon was probably due to the oxidation process of the colour pigments in the meat (Ponnampalam *et al*., 2017). Changes in the meat colour due to lipid oxidation would lead to fading or discolouration (Suman and Joseph, 2013). In contrast, Soni *et al*. (2018) reported that L* values of chicken meat packed in PET boxes stored at refrigeration temperature increased significantly. The increasing L* value could be influenced by the packaging application that protects the sample from oxygen exposure, minimizing the detrimental effect. According to Paião *et al*. (2013), the L* value was influenced by the pH level where lower pH tended to give a high L* value and higher pH gave a lower L* value. The measured pH in this study increased during storage, explaining the decrease in L* during storage was reliable. The reduction in the L* value during chicken meat storage was also in agreement with the research reported by Zhang *et al*. (2016) for untreated chicken meat and Kim *et al*. (2017) for chicken meat at refrigerated storage. Aziz *et al*. (2020) also reported a significant decrease in the L* value after 72 hrs of storage.

The trend of a* value during storage did not differ from initial to final conditions, but it seemed to increase after 24 hrs of storage. The values were found almost constant, about 6. The phenomenon aligns with previous research for chicken breast meat stored at room temperature, where a* value of the chicken meat was not affected by storage time (Castromán *et al*., 2013). According to this study, the a* value could not be used to characterize the chicken meat's freshness or quality during storage. Zeola *et al*. (2002), found that commercial broilers showed pale pink breasts and less reddish, explaining a lower a* value observed in this study. Another study reported that chicken meat under refrigeration storage (4°C) and freezing temperature (-18°C) showed a decrease in the redness value after long-term storage, indicating that the globin might be denatured during storage (Aziz *et al*., 2020).

For the value of b*, it was observed that this value consistently increased during 24 hrs of storage, especially after the 6th hr. This value increased about 75% during 24 hrs of storage or 3.125%/hr. This result followed previous studies, where the b* value of chicken breast meat was higher at 24 hrs than at 3 hrs post-mortem during 24-hr storage at room temperature (Castromán *et al*., 2013). Increasing b* value indicated a rise in the chicken meat yellowness. Zhang *et al*. (2016) reported an increase in yellowness (b*) value for raw chicken meat stored at 4 ◦C for 15 days. An increase in yellowness (b*) value was also found by Soni *et al*. (2018) for chicken meat packed in PET boxes during refrigerated storage. From those findings, it could be concluded that colour attributes of L* and b* could describe the change in the freshness of the chicken meat sample during storage. In this study, the colour sensor used in the apparatus could detect the transformation of the chicken meat colour.

3.5 Performance test on pH of the chicken meat sample

Figure 7 shows the changes in the pH value of the chicken meat sample during 24 hrs of storage. It could be observed that the initial pH of chicken meat was about 6.5, tended to increase slowly, and at the end of the storage period, the value reached about 7. In the normal condition, the pH before slaughter was around 6.5 (neutral), and then in fresh meat, the pH decreased slightly (Committee, 2015). Some parameters were associated with meat decomposition and microbial growth, such as pH shifting (Boziaris *et al*., 2011). This study found that the change in the pH of the sample during storage was 5.6% or 0.233%/hr. These pH changes could be detected by the sensor used in the apparatus, which meant that the sensor used was capable of detecting pH changes in the sample, and pH could be used as one of the indicators to evaluate the freshness of

https://doi.org/10.26656/fr.2017.7(2).024

the chicken meat sample.

Febrianta *et al*. (2021) also used pH as a quality indicator during meat storage. They reported a similar pattern where the pH value during storage changed from pH 5.90 at the initial condition to 6.16 after being stored for 12 days in refrigerated condition. An increasing pH value was also experienced by Kuswandi *et al*. (2014) for chicken cut samples at room temperature and Kim *et al*. (2017) for chicken breast at refrigerated storage. Increased pH values resulted from TVB-N compounds such as NH_3 accumulation (Farahnaz *et al*., 2016). Further, Lactic Acid Bacteria (LAB) affected ammonia development, which increased the pH value (Morgado *et al*., 2018).

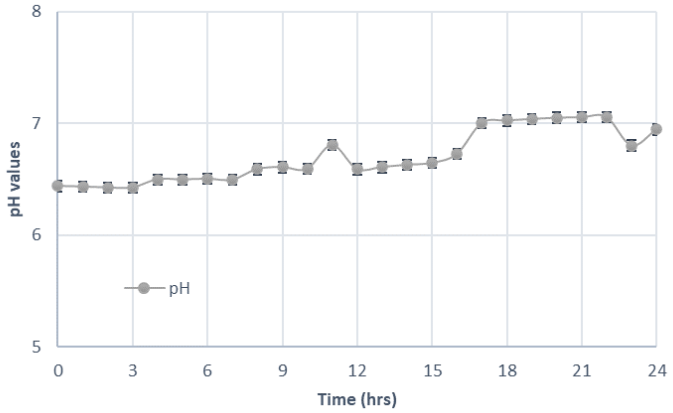


Figure 7. Changes in pH on chicken meat samples stored at room temperature

3.6 Performance test on ammonia and hydrogen sulfide of the chicken meat sample

Figure 8 shows the changes in H_2S and NH_3 gas concentrations of the chicken meat sample during 24 hrs of storage. It could be observed that the concentration of H_2S and NH_3 gases increased along with the storage time. The H_2S concentration changed slowly until 10 hrs of storage. However, it rose significantly after that and increased after 20 hrs of storage (Figure 8a). This phenomenon aligns with the previous research conducted by Li and Suslick (2016), where chicken meat stored at 24°C starts producing H_2S compound at a noticeable amount after 24 hrs of storage and continues increasing until 100 hrs of storage. The concentration of H_2S increased considerably during the initial 12 hrs of storage, then tended to constant from 12 to 21 hrs of storage, and finally increased by more than 300% from 21 to 24 hrs of storage. These captured changes indicated that the sensor used could detect the fluctuation of the H_2S released from the meat sample. The released H_2S was found to be relatively high, which could be used as the parameter to detect the freshness of the chicken meat.

The concentration of NH_3 consistently increased during 24 hrs of storage (Figure 8b). This finding follows the earlier study conducted by Farahnaz *et al*. (2016) that found an increasing concentration of NH_3 gas at all storage temperature variations from 0° to 15°C for chicken breast meat. It was observed that NH_3 increased considerably by more than 6,000% during 15 hrs of storage, then raised more than 600% from 15 to 23 hrs of storage, and finally increased more than 100% at the last 1 hr of storage. This phenomenon also indicated that the sensor used was capable of detecting the change in NH_3 released from the meat sample. NH_3 could also be used as an indicator to detect the freshness of the chicken meat.

According to Li and Suslick (2016), the determination of chicken meat freshness level during storage at 24°C using H_2S, amine, cadaverine, and dimethyl sulfide indicators reported that the chicken meat was in the less fresh category after being stored for 12 hrs and became rotten at 48 hrs of storage. The result also agreed with the findings of Kozacinski *et al*. (2012) in pre-packed cut chicken meat at refrigerated storage, where the chicken meat spoiled at an ammonia level of 9 mg NH_3/100 g of sample. According to the study, the values of L*, b*, pH, H_2S, and NH_3 of the chicken meat for 12 hrs of storage were 50.34, 17.26, 6.59, 134.08 ppm, and 42.34 ppm, respectively. Table 1 the change of those freshness attributes determined every 6 hrs for 24 hrs of storage.

4. Conclusion

The apparatus for detecting the freshness or quality of chicken meat had been developed and tested with

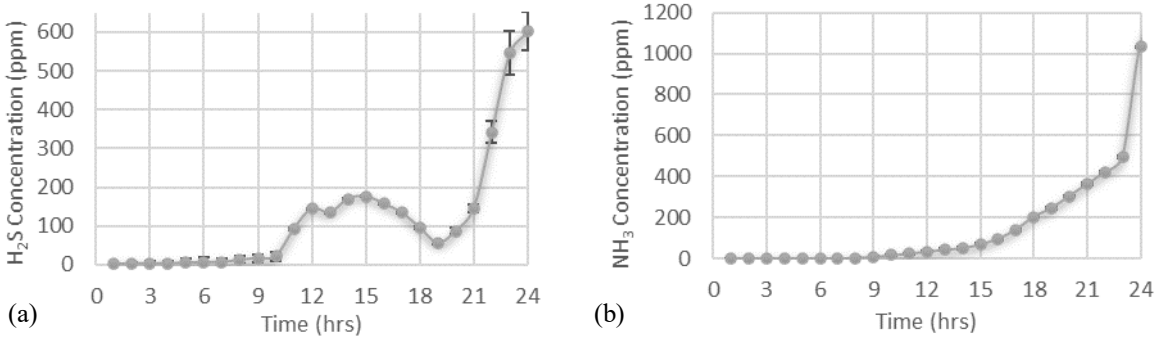
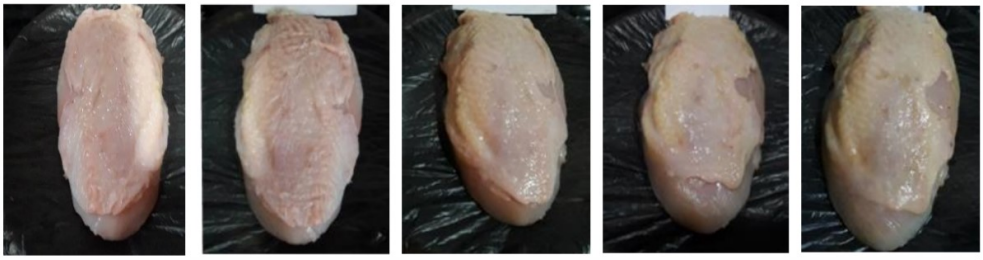


Figure 8. (a) Changes of H_2S and (b) Changes of NH_3 on chicken meat samples stored at room temperature

https://doi.org/10.26656/fr.2017.7(2).024

Table 1. Freshness attributes change of the chicken meat during storage at room temperature

Attributes	Storage Period (hour)				
	0	6	12	18	24
L*	50.55	51.93	50.34	46.96	42.39
b*	12.69	13.58	17.26	20.15	21.28
pH	6.44	6.50	6.59	7.03	6.94
H_2S (ppm)	1.70	6.86	134.08	56.42	679.63
NH_3 (ppm)	0.99	1.17	42.34	245.60	1169.85
Meat appearance					

satisfactory results. The developed apparatus was movable, simple, cheap, easy to operate, and suitable to be used by meat sellers or related institutions. The designed device consisted of four sensors of TCS 3200, PH-98108, MQ 137, and MQ 136 for detecting the colour, pH, NH_3 gas, and H_2S gas of the sample, respectively. The sensors used could detect the intended parameters of colour, pH, NH_3 gas, and H_2S and might monitor the change in chicken meat freshness during storage. The parameters of L*, b*, pH, H_2S, and NH_3 gas were adequate to detect the freshness of chicken meat. If the chicken meat was considered less fresh after being stored for 12 hrs, the L*, b*, pH, H_2S, and NH_3 gas values were 50.34, 17.26, 6.59, 134.08 ppm, and 42.34 ppm, respectively.

Conflict of interest

The authors declare that there is no conflict of interest in publishing this research work.

Acknowledgements

The author would like to thank LPDP (Indonesia Endowment Fund for Education), the Ministry of Finance, of the Republic of Indonesia for the financial support provided in this research and Gadjah Mada University for facilitating laboratory equipment.

References

Aziz, M.F.A., Hayat, M.N., Kaka, U., Kamarulzaman, N.H. and Sazili, A.Q. (2020). Physico-Chemical Characteristics and Microbiological Quality of Broiler Chicken Pectoralis Major Muscle Subjected to Different Storage Temperature and Duration. *Foods*, 9(6), 741–753. https://doi.org/10.3390/foods9060741

Boronkay, G. (2013). Colour Conversion Centre. Retrieved on October 31, 2021 from http://ccc.orgfree.com/

Boziaris, I.S., Kordila, A. and Neofitou, C. (2011). Microbial spoilage analysis and its effect on chemical changes and shelf-life of Norway lobster (*Nephrops norvegicus*) stored in air at various temperatures. *International Journal of Food Science and Technology*, 46(4), 887–895. https://doi.org/10.1111/j.1365-2621.2011.02568.x

Castromán, G., Puerto, M.D. and Ramos, A. (2013). Organic and Conventional Chicken Meat Produced in Uruguay: Colour, Ph, Fatty Acids Composition and Oxidative Status. *American Journal of Food and Nutrition*, 1(2), 12–21. https://doi.org/10.12691/ajfn-1-2-2

Edita, R., Darius, G., Vinauskienė, R., Eisinaitė, V., Balčiūnas, G., Dobilienė, J. and Tamkutė, L. (2018). Rapid evaluation of fresh chicken meat quality by electronic nose. *Czech Journal of Food Sciences*, 36 (5), 420–426. https://doi.org/10.17221/419/2017-CJFS

Ephipanias, R. (2018). Perancangan pendeteksi amonia menggunakan sensor mq-137 dengan software visual basic berbasis mikrokontroller atmega. Medanm Indonesia: Universitas Sumatera Utara. BSc. Thesis. [In Bahasa Indonesia].

Farahnaz, G.-M., Reza Housaindokht, M., Mohsenzadeh, M. and Varidi, M. (2016). Microbial and chemical spoilage of chicken meat during storage at isothermal and fluctuation temperature under aerobic conditions. *Iranian Journal of Veterinary Science and Technology*, 8(1), 38–46. doi:10.22067/veterinary.v8i1.54563

Febrianta, H., Yunianto, V.D., Nurwantoro, N. and Bintoro, V.P. (2021). Quality evaluation of chicken breast marinated with encapsulation of turmeric extract. *Food Research*, 5(4), 366–373. https://doi.org/10.26656/fr.2017.5(4).066

Hunt, M.C. and King, D.A. (2012). AMSA. Meat Color

Measurement Guidelines. In American Meat Science Association. Illinois: AMSA.

Kamruzzaman, M., Barbin, D., Elmasry, G., Sun, D.W. and Allen, P. (2012). Potential of hyperspectral imaging and pattern recognition for categorization and authentication of red meat. *Innovative Food Science and Emerging Technologies*, 16, 316–325. https://doi.org/10.1016/j.ifset.2012.07.007

Kamruzzaman, M., Makino, Y. and Oshita, S. (2015). Non-invasive analytical technology for the detection of contamination, adulteration, and authenticity of meat, poultry, and fish: A review. *Analytica Chimica Acta*, 853(1), 19–29. https://doi.org/10.1016/j.aca.2014.08.043

Kartika, V.S., Rivai, M. and Purwanto, D. (2018). Spoiled meat classification using semiconductor gas sensors, image processing and neural network, presented at the 2018 International Conference on Information and Communications Technology, ICOIACT., p. 418–423. Yogyakarta, Indonesia. https://doi.org/10.1109/ICOIACT.2018.8350678

Kementan. (2020). Statistik Peternakan dan Kesehatan Hewan 2020. 1st ed. Jakarta, Indoensia: Direktorat Jenderal Peternakan dan Kesehatan Hewan, Kementerian Pertanian RI.

Kim, D., Lee, S., Lee, K., Baek, S. and Seo, J. (2017). Development of a pH indicator composed of high moisture-absorbing materials for real-time monitoring of chicken breast freshness. *Food Science and Biotechnology*, 26(1), 37–42. https://doi.org/10.1007/s10068-017-0005-6

Kozacinski, L., Fleck, Ž.C., Kozacinski, Z., Filipovic, I., Mitak, M., Bratulic, M. and Mikuš, T. (2012). Evaluation of shelf life of pre-packed cut poultry meat. *Veterinarski Arhiv*, 82(1), 47–58.

Kuswandi, B., Jayus, Oktaviana, R., Abdullah, A. and Heng, L.Y. (2014). A Novel On-Package Sticker Sensor Based on Methyl Red for Real-Time Monitoring of Broiler Chicken Cut Freshness. *Packaging Technology and Science*, 27(1), 69–81. https://doi.org/10.1002/pts.2016

Lee, H., Chung, C.H., Kim, K.B. and Cho, B.K. (2010). Evaluation of freshness of chicken meat during cold storage using a portable electronic nose. *Korean Journal for Food Science of Animal Resources*, 30 (2), 313–320. https://doi.org/10.5851/kosfa.2010.30.2.313

Li, Z. and Suslick, K.S. (2016). Portable Optoelectronic Nose for Monitoring Meat Freshness. *ACS Sensors*, 1(11), 1330–1335. https://doi.org/10.1021/acssensors.6b00492

Mead, G.C. (2004). Microbiological quality of poultry meat: a review. *Brazilian Journal of Poultry Science*, 6(3), 135–142. https://doi.org/10.1590/s1516-635x2004000300001

Metrohm International Headquarters, C.C.T. (1991). pH measurement technique. Application Bulletin 188/4 e. Retrieved from website: https://www.metrohm.com/content/dam/metrohm/shared/documents/application-bulletins/AB-188_4.pdf

Morgado, C., Pestana, J.M., Guerra, M.M. and Brandão, C. (2018). Microbiological quality in convenient ready-to-eat vegetables during shelf life. *AIMS Agriculture and Food*, 3(4), 372–383. https://doi.org/10.3934/AGRFOOD.2018.4.372

Paião, F.G., Ferracin, L.M., Pedrão, M., Kato, T. and Shimokomaki, M. (2013). Skeletal muscle calcium channel ryanodine and the development of pale, soft, and exudative meat in poultry. *Genetics and Molecular Research*, 12(3), 3017–3027. https://doi.org/10.4238/2013.August.20.3

Ponnampalam, E.N., Hopkins, D.L., Giri, K., Jacobs, J.L., Plozza, T., Lewandowski, P. and Bekhit, A. (2017). The use of oxidative stress biomarkers in live animals (*in vivo*) to predict meat quality deterioration postmortem (in vitro) caused by changes in muscle biochemical components. *Journal of Animal Science*, 95(7), 3012–3024. https://doi.org/10.2527/jas2016.0887

Poynton, C. (2005). Sensing color with the TAOS TCS230 in Digital Video and HDTV Algorithms and Inter- faces, p. 1–15. San Francisco, USA: Morgan Kaufmann Publishers Inc.

Prasojo, E. (2017). Rancang Bangun Sistem Kontrol Kadar Has H2S Pada Proses Purifikasi Biogas Dengan Water Scrubber System Berbasis Microcontroler Atmega128. Surabaya, Indonesia: Institut Teknologi Sepuluh Nopember [In Bahasa Indonesia].

Qiu, S. and Wang, J. (2017). The prediction of food additives in the fruit juice based on electronic nose with chemometrics. *Food Chemistry*, 230, 208–214. https://doi.org/10.1016/j.foodchem.2017.03.011

Raudienė, E., Gailius, D., Vinauskienė, R. and Eisinaitė, V. (2018). Rapid Evaluation of Fresh Chicken Meat Quality by Electronic Nose. *Czech Journal of Food Sciences*, 36(5), 420–426. https://doi.org/10.17221/419/2017-CJFS

Sari, D., Suyati, L., dan Widodo, D.S. (2016). Pengaruh Buffer Kalium Fosfat dan Natrium Fosfat terhadap Produksi Listrik dalam Sistem Microbial Fuel Cell (MFC) dengan *Lactobacillus bulgaricus* pada Whey Tahu. *Jurnal Kimia Sains Dan Aplikasi*, 19(3), 107–110. https://doi.org/10.14710/jksa.19.3.107-110 [In

Bahasa Indonesia].

Schneider, A.C., Pasel, C., Luckas, M., Schmidt, K.G. and Herbell, J.D. (2004). Determination of Hydrogen Single Ion Activity Coefficients in Aqueous HCl Solutions at 25°C. *Journal of Solution Chemistry*, 33 (3), 257–273. https://doi.org/10.1023/B:JOSL.0000035359.00943.14

Sendari, S., Hadi, M.S., Rahmawati, Y., Hadi, N.C., Wibowo, F.S., Wibowo, D.A., Agustin, W., Kumalasari, I., Rachman, I. and Matsumoto, T. (2019). Design and analysis of safety hazardous gas instruments for laboratory experiments. *AIP Conference Proceedings*, 2173, 5133921. https://doi.org/10.1063/1.5133921

Shukla, V., Kandeepan, G. and Vishnuraj, M. R. (2015). Development of on package indicator sensor for real-time monitoring of meat quality. *Veterinary World*, 8 (3), 393–397. https://doi.org/10.14202/vetworld.2015.393-397

Smith, D.P. and Northcutt, J.K. (2009). Pale poultry muscle syndrome. *Poultry Science*, 88(7), 1493–1496. https://doi.org/10.3382/ps.2008-00509

Soni, A., Mendiratta, S.K., Talukder, S., Kumar, R., Chand, S. and Jaiswal, R.K. (2018). Development of Colorimetric On-package Indicator for Monitoring of Chicken Meat Freshness during Refrigerated Storage (4±1°C). *Journal of Animal Research*, 8(5), 847–853. https://doi.org/10.30954/2277-940X.10.2018.16

Sudarmaji, A., Margiwiyatno, A., Sulistyo, S.B. and Saparso (2021). Measurement of Patchouli oil vapor using array of MOS gas sensors in various adulteration substances and concentrations. *Food Research*, 5(S2), 84–90. https://doi.org/10.26656/fr.2017.5(S2).016

Suman, S.P. and Joseph, P. (2013). Myoglobin chemistry and meat color. *Annual Review of Food Science and Technology*, 4(1), 79–99. https://doi.org/10.1146/annurev-food-030212-182623

Zeola, N.M.B.L., Silva Sobrinho, A.G., Neto, S.G. and Silva, A.M.A. (2002). Influência de diferentes níveis de concentrado sobre a qualidade da carne de cordeiros Morada Nova. *Revista Portuguesa de Ciências Veterinárias*, 97(554), 175–180. [In Portuguese].

Zhang, H., Wu, J. and Guo, X. (2016). Effects of antimicrobial and antioxidant activities of spice extracts on raw chicken meat quality. *Food Science and Human Wellness*, 5(1), 39–48. http://dx.doi.org/10.1016/j.fshw.2015.11.003

https://doi.org/10.26656/fr.2017.7(2).024