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Research Paper

Detection of Food Freshness in Chicken Meat Based on Weight Variations Using ZnO Gas Sensor

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Abstract

In today's food industry, ensuring the safety and quality of chicken meat is important for protecting the public's health and top priority for both consumers and producers. Reliable detection methods are important to address concerns about eating low-quality chicken meat, especially when determining its freshness or food contamination. Therefore, this study proposed a gas sensor as a device to sense the released gas from the chicken meat at a certain time. The ZnO gas sensor was exposed to the chicken meat based on various weights: 200 g, 100 g, 50 g, 25 g, and 10 g at room temperature for 24 hours. The ZnO gas sensor was fabricated using a screen-printing method on a Kapton film. Integrating the gas sensor with an IoT platform by using the Blynk application makes it easier to monitor and identify freshness in real-time applications. The results highlighted that the highest sensing response value was 55 by ZnO-3 when exposed to the 200 g chicken breast. The average time for chicken breast to be spoiled was approximately 20 hours for all weights of chicken breast, which are 200 g, 100 g, 50 g, 25 g, and 10 g. The results showed that the fabricated ZnO gas sensor outperformed the commercial sensor, MQ137, in detecting the gas released from the chicken meat. Thus, this gas sensor can be used to sense odor gases from the chicken meat.

Keywords: *Blnyk application; chicken breast; food quality and freshness; screen printing; thick film gas sensor.*

Introduction

In today's food industry, ensuring the safety and quality of chicken meat is important for protecting the public's health, and it remains a top priority for both consumers and producers. It is an important issue of food quality, especially in chicken meat, the risk of spoilage and bacterial contamination, which may lead to serious health risks such as nausea, diarrhea, abdominal pain, fever, and in severe cases, vomiting and even death (Rouger et al., 2017). Older people, pregnant women, those with weakened immune systems, children, and newborns are among the high-risk groups. Volatile organic compounds (VOCs) and toxic gases, such as hydrogen sulfide, ammonia, and other spoilage signs, are the main causes of the rapid degradation of chicken meat quality (Han et al., 2024; Alam et al., 2024). However, it is challenging to accurately determine the freshness of meat due to the lack of an efficient and real-time monitoring system, which could result in risks to food safety as well as financial losses (Fletcher et al., 2018). Furthermore, the analysis process may become more complex due to human error, such as transcription errors or inaccurate data entry, as each phase of the analysis involves manual data recording (Al Isyrofie et al., 2022; Brous et al., 2020). Conventional techniques for assessing the quality of chicken meat, like microbiological testing and sensory inspection, can be labor-intensive, time-consuming, and unsuitable for real-time applications (Husin et al., 2020).

According to data from the Centers for Disease Control and Prevention, approximately 1 in 6 Americans suffer from foodborne illnesses annually, with poultry products being a significant source of contamination (Silva et al., 2023; Rouger et al., 2017). Innovative and dependable detection techniques that can accurately determine the quality of chicken meat need to be developed in response to these concerns. These techniques must provide objective,

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scientifically validated freshness and safety measurements in addition to the normal subjective evaluations. These detection techniques enable suppliers to maintain high standards of quality throughout the supply chain while also helping customers to make carefully considered choices about the quality of chicken meat. Furthermore, spending money on reliable detection technology promotes accountability and transparency in the food sector, in addition to increasing customer's confidence. Therefore, the development and application of reliable detection techniques for food quality highlights a common commitment to public health and ensures that food quality satisfies the highest standards for quality and safety. Thus, there is a need for such gas sensor that highly sensitive, cost-effective, non-destructive, and easy-to-handle to handle to monitor the freshness of chicken meat.

Currently, metal oxide semiconductors are widely used and promising materials used as sensing materials in gas sensors to detect various types of gases. Three common metal oxide semiconductors such as zinc oxide (ZnO) (Y. Y. Guo et al., 2025), titanium dioxide (TiO_2) (Chachuli et al., 2022; Haidry et al., 2025), and tin dioxide (SnO_2) (An et al., 2024; Yong et al., 2025). The ability to detect the gas that are more sensitive, stable responses, and low-cost, real-life applications-based gas sensors are always needed in gas sensors (Goel et al., 2023). Among metal-oxide semiconductors, ZnO has been seen as a promising candidate because this material is reported to sense better than other materials in detecting the released gases (Bhati et al., 2020). These chemical-based gas sensors are reliable for experimental applications since they can detect the gases released from spoiled chicken (W. Guo et al., 2012). Therefore, this study proposes ZnO as a sensing material for gas sensors to detect the quality of chicken meat. ZnO offers a low-cost, effective, and real-time monitoring system (Alam et al., 2024). Other than that, ZnO also has great sensitivity and stability, guaranteeing quick and precise detection of spoiling gases (Ma et al., 2023). With these features, it is believed that ZnO can be a promising sensing material to detect chicken freshness.

Rapid development of technologies, research on food quality monitoring has gained interest by researchers to ensure the safety and quality of the food. Sensors have been used as a detector device in food industries, such as in the sector of food packaging (Siciliano et al., 2025) and emission gases from food (Chu et al., 2025; Li et al., 2025). Various gases, including ethylene (C_2H_4), ammonia (NH_3), ethylmethylamine (C_3H_9N), and hydrogen sulfide (H_2S), can be generated during the spoilage or ripening process of food, providing insights into the state of food freshness (Park et al., 2024). Reported that resistance-based gas sensors based on metal-oxide have been used to detect emission gases from food, such as ZnO (Fernández-Ramos et al., 2025; Li et al., 2025), and tungsten oxide (Liang et al., 2025). In chicken meat detection, fabricated gas sensors (Nami & Deen, 2025) and commercial sensors (Al Isyrofie et al., 2022) have been used to detect ammonia released from chicken meat. Therefore, it is believed that ZnO can be used as a promising material to detect ammonia from chicken breast in this study.

These days, there is a growing demand for the use of IoT integration with sensors in new developments and applications (Yamini et al., 2024). With the rapid development of technologies, many research studies have integrated sensors with Internet of Things (IoT) platforms such as Blynk (Jena et al., 2023; Omran et al., 2022), Thingspeak (Chachuli et al., 2024; Guvvala & Ch, 2023), and Adafruit (Juel et al., 2019; Narayana et al., 2024) for real-time monitoring and fast detection. Among all platforms, most features were similar, where the data can be monitored on mobile or desktop. Thus, all platforms can be used to integrate with the gas sensor. The IoT technology makes it possible to track the data every minute, which can help in a gas leakage or gas detection system. In this study, Blynk software has been chosen as the IoT platform because this platform was easy to develop with a simple algorithm.

This study presents ZnO gas sensors to detect the released gases from chicken meat by monitoring with Blynk software for a real-time monitoring system. The ZnO gas sensor was fabricated using a screen-printing technique and exposed to five different weights of chicken meat at a room temperature of 25 °C. The results showed that all ZnO gas sensors can identify the gas release from spoiled chicken breast at room temperature for weights in the range of 10 – 200 g. A higher sensing response was generated by the chicken breast with a weight of 200 g. By implementing the gas sensor with an IoT application, a real-time food monitoring system can provide consumers with safer and better-quality meat products in the future, and also support the supply chain system.

Methodology

Materials Specification

Ethyl cellulose (48.0 - 49.5% (w/w), ethoxyl basis), alpha-terpineol (97%), and ZnO powder were purchased from Sigma-Aldrich, Acros Organics, and Chemiz (M) Sdn Bhd, respectively. All materials were used without purification.

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Fabrication of ZnO Gas Sensor via Screen Printing Technique

The fabrication process of the ZnO gas sensor via the screen-printing technique is shown in Figure 1. Firstly, 95 wt. % of alpha-terpineol and 5 wt. % of ethyl cellulose to produce 10 g of binder. This describes 0.5 g of ethyl cellulose and 9.5 g of terpineol. This mixture can be done by using a magnetic stirrer for the mixing process, stirred continuously for 24 hours at a temperature of 40 °C and a stirring speed of 250 rpm. The preparation of ZnO paste, a combination of 50 wt. % of binder and 50 wt. % of ZnO powder, which is 1.5 g of binder and 1.5 g of zinc oxide powder, is needed to make 3 g of ZnO paste. The mixture was stirred at a temperature of 30 °C and the speed of the stirrer at 100 rpm. Initially, the substrate was prepared in a size of 2 cm x 2 cm. The ZnO gas sensor consists of two layers, where the first layer is an interdigitated electrode and the second layer is the sensing layer. Firstly, the silver paste was deposited on the Kapton film using a screen-printing technique for the electrode layer, which is based on interdigitated electrodes. To ensure the silver paste remains on the substrate, the silver paste was annealed at 150 °C for 30 minutes in an oven. Next, the ZnO paste was deposited onto the interdigitated electrode to create the sensing layer using a screen-printing technique and annealed at 200 °C for an hour in an oven. After that, the legs of the interdigitated electrode were connected to the copper wires with silver paste used to create an electrical connection. The ZnO gas sensor was heated one more time for 15 minutes at 150 °C to cement the connection.

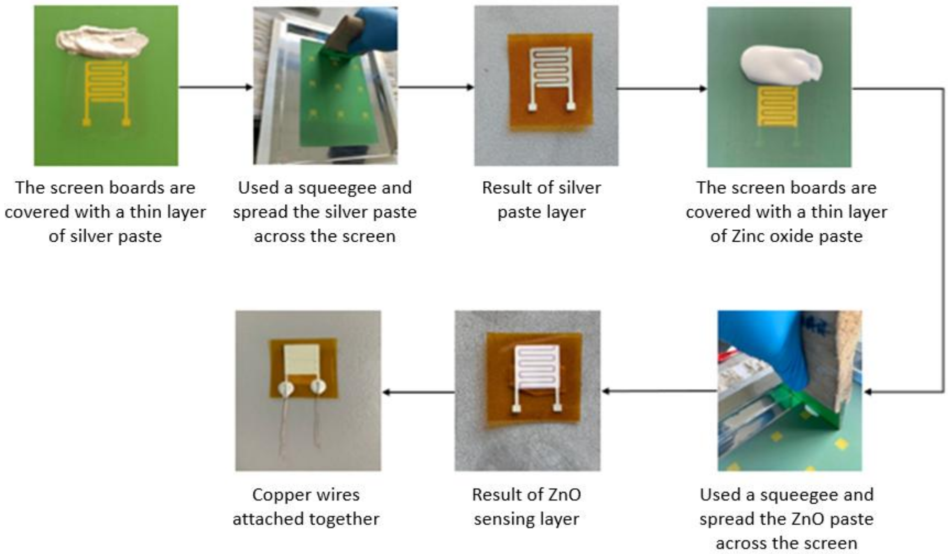


Figure 1 Fabrication process of ZnO gas sensor via screen-printing technique.

Every weight of chicken meat will be exposed to the three samples of ZnO gas sensors; thus, 15 samples of ZnO gas sensors were needed in this study. 15 samples of ZnO gas sensors were labeled as ZnO-1 to ZnO-15 as presented in Figure 2. It can be seen that all the sensing layers of ZnO gas sensors were in white color, which showed the uniformity of ZnO as the sensing layer based on the screen-printing technique.

Integration of ZnO Gas Sensor with IoT Blynk Application

In order to record the data of chicken meat in 24 hours, the ZnO gas sensor was connected to the Blynk application to monitor the voltage reading in real-time applications. Figure 3 shows the circuit diagram of the fabricated ZnO gas sensor with the ESP32 microcontroller, LCD display, and buzzer. The ESP32 was chosen because it has several analog pins, which are necessary for connecting different sensors, and an integrated Wi-Fi module that makes it easy to integrate with IoT platforms for real-time monitoring. The two electrode pins that connected to the fabricated gas sensor's electrode layer were connected to the GPIO32, GPIO33, and GPIO35 for 3 gas sensors on the board and a 5V power supply. Three samples of ZnO gas sensors were connected for each weight of chicken breast (200 g, 100 g, 50 g, 25 g, and 10 g) to gather data on voltage to determine which of the sensors is more sensitive and efficient in detecting spoilage chicken breast. The system consists of a 20 x 4 LCD, LED, and buzzer that function to display the voltage response during the exposure process. The buzzer will sound, and the LED will turn on when the response reaches 3.3V, which indicates the chicken was spoiled.

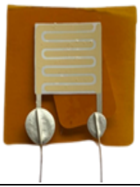
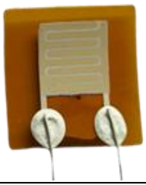
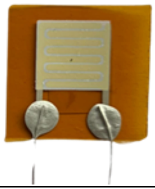
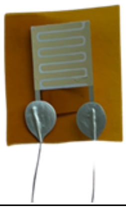
Weight of chicken breast	Sample name		
200	 ZnO-1	 ZnO-2	 ZnO-3
100	 ZnO-4	 ZnO-5	 ZnO-6
50	 ZnO-7	 ZnO-8	 ZnO-9
25	 ZnO-10	 ZnO-11	 ZnO-12
10	 ZnO-13	 ZnO-14	 ZnO-15

Figure 2 Fabricated ZnO gas sensors using the screen-printing technique.

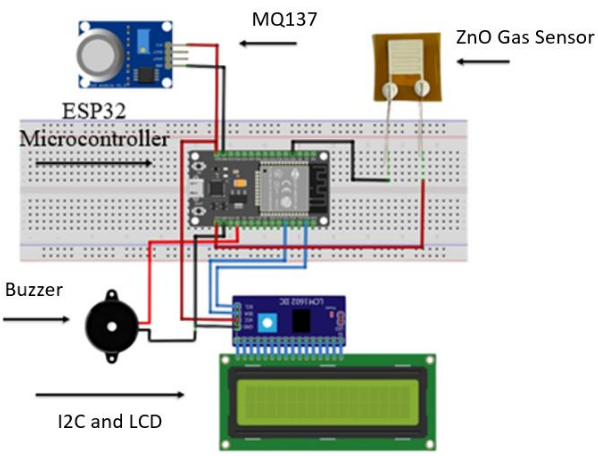


Figure 3 Circuit Diagram of ZnO Gas Sensor with IoT Blynk.

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Experimental Setup of Exposure to Chicken Meat

Figure 4 shows the experimental setup for the ZnO gas sensor exposure to chicken meat. Chicken breast meat was chosen for testing because of its uniform composition and higher susceptibility to bacterial contamination and spoiling, in order to be suitable for standard evaluations. Firstly, the voltage of the three samples of ZnO gas sensors was monitored until it reached a stable value. The chicken breast (200 g, 100 g, 50 g, 25 g, and 10 g) needs to defrost for 30 minutes to ensure it is fully defrosted and ready for the exposure process. Next, the gas sensors were placed on the cover sensor at the container lid. Then, the exposure process will start by placing the chicken breast into the container and sealing the container with plastic wrap to ensure the gas emission from the chicken breast does not escape outside the lid. The voltage of the ZnO gas sensors was monitored over 24 hours using Blynk software. The voltage was recorded for 1 hour for 1 data point over 24 hours of the exposure process, then the data were plotted using the Origin 2019b software.

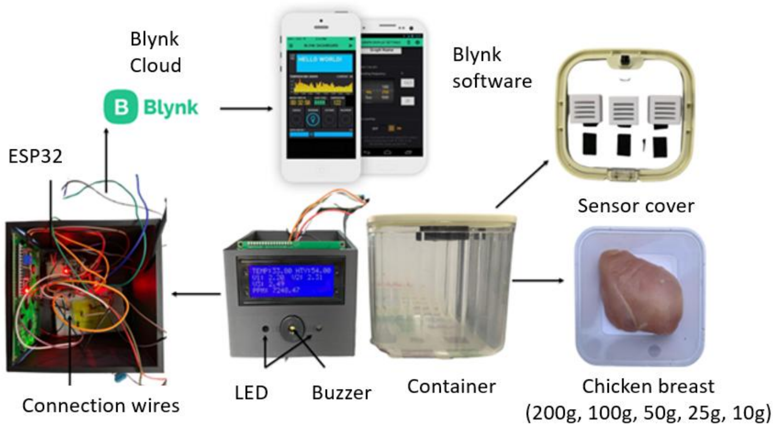

Figure 4 Experimental Setup of ZnO Gas Sensor to chicken meat.

Results

Current – Voltage (I-V) Measurement

Figure 5 shows I-V characteristics for 15 samples of ZnO gas sensors in the range -10 V to 10 V. The I-V characterization result showed the linearity of ZnO gas sensors, which follows Ohm's law. These results support that the voltage across the two points is directly proportional to the current flowing through a sensor, a linear connection between current and voltage. The I-V measurement is needed to confirm the linearity, and is an essential method to verify that the sample can be exposed to chicken meat. It is important to obtain a linear graph for a resistance-based gas sensor, where only a linear gas sensor can be exposed to the target gas. Linearity of the resistance-based gas sensor has also been discussed in a prior study (Chachuli et al., 2025). From the I-V graph, the resistance of the gas sensor was calculated by using Eq. (1):

$$Resistance = \frac{1}{slope\ of\ I{-}V\ graph} \tag{1}$$

where the slope of the I-V graph can be obtained from the Origin 2019b software by applying linear fitting to the graph.

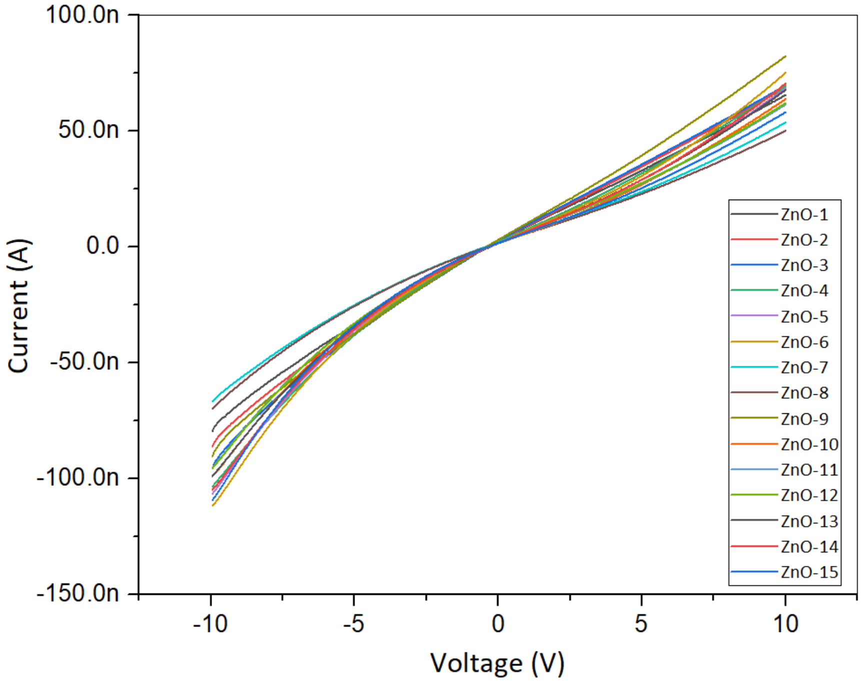

Figure 5 I-V Characteristic of ZnO gas sensors.

Table 1 lists the resistance value for 15 samples of ZnO gas sensors. The results observed that the resistance for the ZnO gas sensor was in the range of 120 – 150 MΩ. The lowest resistance was produced by ZnO-6 at 123.61MΩ, while the highest resistance was produced by ZnO-1 at 145.07 MΩ. The resistance values were controlled to ensure the performance during the exposure process was in good alignment with the gas sensing requirements, especially when it comes to detecting the volatile organic compounds (VOCs) that are released from chicken meat. If the resistance of the ZnO gas sensor is not in the range of 120 – 150 MΩ, the gas sensor cannot be exposed to the chicken meat. All the ZnO gas sensors will be exposed to the various weights of chicken breast for 24 hours at room temperature.

Table 1 Resistance of ZnO gas sensors

Weight (g)	Gas Sensor	Resistance (MΩ)
200	ZnO-1	145.07
	ZnO-2	136.49
	ZnO-3	129.54
100	ZnO-4	127.55
	ZnO-5	130.89
	ZnO-6	123.61
50	ZnO-7	140.15
	ZnO-8	127.61
	ZnO-9	123.72
25	ZnO-10	140.25
	ZnO-11	144.51
	ZnO-12	143.67
10	ZnO-13	135.87
	ZnO-14	131.06
	ZnO-15	140.06

Characterization of Sensing Layer Using XRD and FESEM

Figure 6 illustrates the XRD Spectra of the ZnO Sensing Layer after annealing treatment. According to the results, it was confirmed that the ZnO nanoparticles indicated a high degree of crystallinity with high peaks of phase elements. These peaks represented the material's typical hexagonal wurtzite structure of ZnO. The sharp and clear peaks shown at 2θ angles of 31.7°, 34.4°, 36.3°, 47.5°, 56.6°, and 62.8° in the XRD analysis of pure ZnO (Khan et al., 2024; Kumar & Lamba, 2019; Reddy et al., 2025). These peaks confirmed that the ZnO was a lattice structure by corresponding to its hexagonal

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wurtzite structure. By decreasing lattice defects, the annealing procedure effectively increased crystallinity, which is essential for efficient charge transfer and improved gas sensing capabilities.

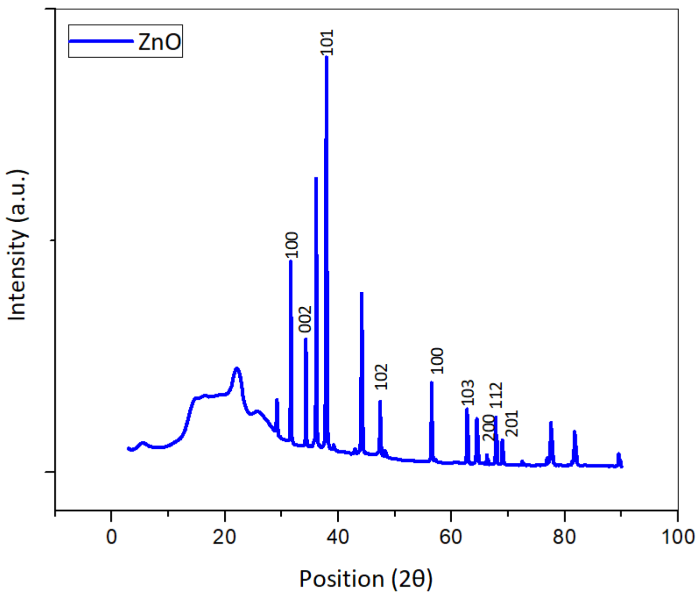

Figure 6 XRD Spectra of ZnO sensing layer.

Figure 7 represents the surface morphology of the ZnO sensing layer after annealing treatment at 200°C, where the shape of ZnO particles varies, such as spheres, rods, and flakes. The structures have a relatively uniform and compact nanostructure and appear as well-formed, packed square or cuboidal structures, as presented in another study (Sayuti et al., 2025).

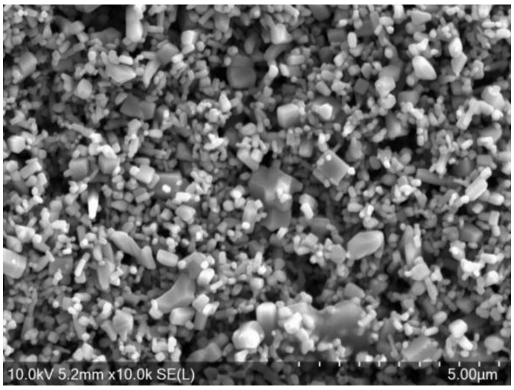

Figure 7 Surface morphology of ZnO sensing layer.

Analysis of ZnO Gas Sensors to Chicken Meat at Room Temperature

Figure 8 shows the sensing response of ZnO sensors (ZnO-1 to ZnO-15) to the various weights of chicken breast over 24 hours. The observed patterns were recorded in voltage responses across different weights of chicken breast. The repeatability testing of the ZnO sensors on the chicken meat was also assessed by exposing three similar samples for each exposure. The results were aligned with n-type gas sensor behavior, where the ZnO gas sensors showed increased voltages when exposed to chicken meat over 24 hours. Variations in initial and maximum voltages were influenced by the gas concentration and proportional to chicken weight. Other than that, environmental factors such as sunlight exposure and air conditioner shutdown can also affect the sensor stability over time. The findings demonstrated that all ZnO gas sensors were capable of detecting gas released from the chicken meat and were also able to achieve saturation voltage in 24 hours.

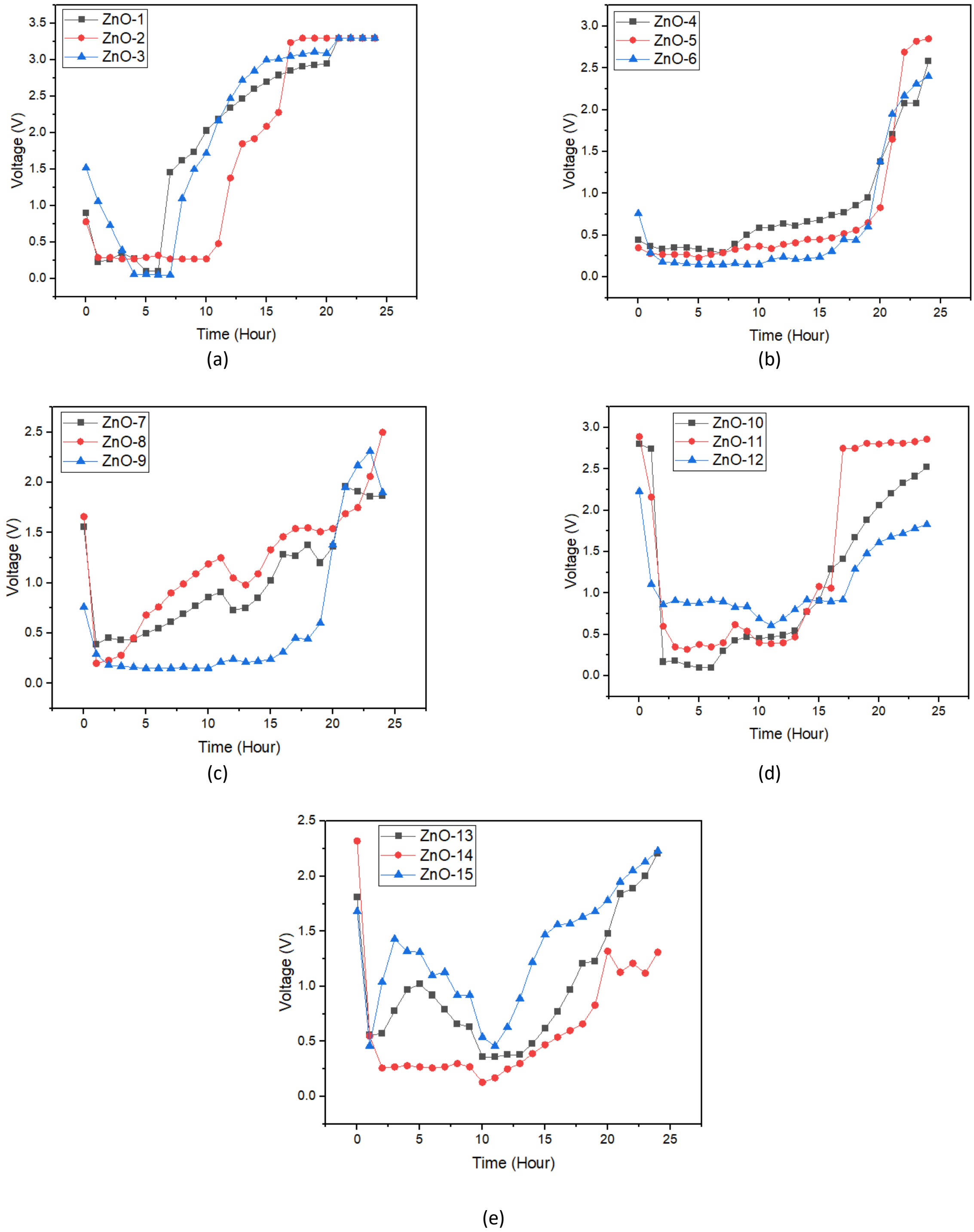

Figure 8 Sensing response of ZnO gas sensors to various weights of chicken breast: (a) 200 g, (b) 100 g, (c) 50 g, (d) 25 g, and (e) 10 g.

Table 2 summarizes the characteristics of ZnO gas sensors when exposed to the gases released from different weights of chicken breast, in terms of sensing response value and freshness level. The sensing response value was calculated as follows:

$$Sensing\ response = \frac{V_{saturated}}{V_{initial}} \quad (2)$$

Where $V_{initial}$ is the voltage taken during a stable value, where the chicken is in fresh/safe condition, while $V_{saturated}$ is the saturated voltage, this voltage did not change after the gas was saturated in the chamber, where in this condition the chicken has already spoiled. The response values showed a trend of decreasing with lower chicken weights, except for ZnO-8, ZnO-9, and ZnO-10, which displayed unexpectedly high sensitivity at moderate weights because of accidental

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exposure to the sunlight. The response times increased as the weight decreased, correlating with lower gas concentrations and slower sensor responses. The highest response was observed for ZnO-3 at 55 for 200 g, while the lowest was for ZnO-12 at 1.99. ZnO-3 consistently exhibited high sensitivity across weights, while ZnO-15 showed the least response for 10 g. The sensors demonstrated good repeatability, with stabilized response times at intermediate weights due to balanced gas diffusion. These findings highlight the impact of gas concentration on the ZnO gas sensor's performance and its potential application for detecting spoilage gases at different concentrations.

Table 2 Sensing response and freshness level of chicken breast

Weight of Chicken Breast (g)	Gas Sensor	Sensing Response Value	Freshness level of chicken breast (Hour)			Average time of spoiled chicken (Hour)
			Fresh/ Safe	Unsafe	Spoiled	
200	ZnO-1	145.07	14.35	0 – 6	7 – 20	20
	ZnO-2	136.49	11.38	0 – 10	11 – 16	
	ZnO-3	129.54	55.00	0 – 7	8 – 20	
100	ZnO-4	127.55	7.82	0 – 7	8 – 21	22
	ZnO-5	130.89	9.83	0 – 7	8 – 21	
	ZnO-6	123.61	13.33	0 – 10	11 – 21	
50	ZnO-7	140.15	5.03	0 – 13	14 – 20	21
	ZnO-8	127.61	12.50	0 – 13	14 – 20	
	ZnO-9	123.72	12.83	0 – 10	11 – 19	
25	ZnO-10	140.25	14.82	0 – 6	7 – 15	17
	ZnO-11	144.51	8.94	0 – 7	8 – 16	
	ZnO-12	143.67	2.13	0 – 9	10 – 17	
10	ZnO-13	135.87	3.88	0 – 13	14 – 20	21
	ZnO-14	131.06	5.04	0 – 9	10 – 19	
	ZnO-15	140.06	4.80	0 – 11	12 – 20	

The freshness level of chicken breast was categorized according to the pattern of the sensor's voltage over 24 hours. At first measurement, the voltages were stabilized; thus, this condition can be considered fresh or safe to eat in the chicken breast. The unsafe condition is categorized as the gas starting to release in the lid of the chicken breast, and the spoiled condition is identified as the voltage being saturated. Based on the average time of spoiled chicken, it can be concluded that most of the chicken breast was spoiled for 20 hours at room temperature, based on the weather in Malaysia. The time for safe and unsafe conditions for chicken breasts varied depending on the weight of the chicken breast. Other than that, the weather in Malaysia can also influence the unsafe condition of chicken meat because Malaysia is located close to the equatorial line, thus sunny and rainy days always occur during the measurements conducted.

Figure 9 presents the error bars of the sensing response based on various weights of chicken breast. It can be seen that the smallest error was produced by the smallest weight of chicken breast, which is 10 g, while the highest error was produced by the largest weight of chicken breast, which is 200 g. The error for 200 g of chicken breast was large because ZnO-2 produced a sensing response of 11.38, while ZnO-3 produced a sensing response of 55.00; thus, the difference between these two values was too large, which was approximately 79.31%, thus a large error was calculated. Meanwhile, the second highest error bar was contributed by chicken breast of 20 g, followed by chicken breast of 50 g and 100 g. The value of sensing response for each ZnO gas sensor must be close to each other for each weight of chicken breast, to obtain low error bar values.

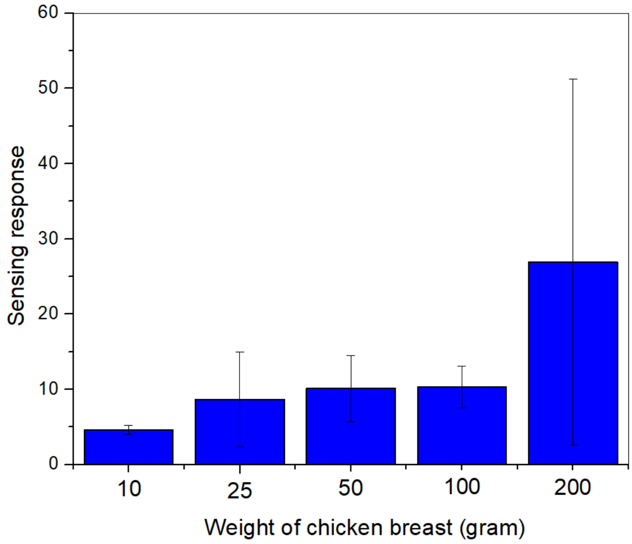

Figure 9 Error bar of the sensing response based on various weights of chicken breast

Comparison Analysis of Fabricated ZnO Gas Sensors with the MQ137 Sensor Module

The fabricated ZnO gas sensor in this study was also compared with the commercial sensor, MQ137. This testing was conducted for 200 g of chicken breast only, since the highest sensing response was produced by this weight. MQ137 was chosen because this sensor module was sensitive to ammonia, where most of the studies reported that chicken meat released ammonia during the spoilage process. Three samples of ZnO gas sensors and the MQ137 sensor module were exposed to 200 g of chicken breast simultaneously for 24 hours at room temperature. The data were monitored using the Blynk application, then recorded in Excel software and plotted using Origin software. Figure 10 shows the voltage response of ZnO sensors (ZnO-1, ZnO-2, and ZnO-3) and MQ137 during exposure to 200 g of chicken breast. MQ137 had an initial voltage of 0.75 V, whereas ZnO-1, ZnO-2, and ZnO-3 had beginning voltages of 0.9 V, 0.78 V, and 0.79 V, respectively. Early in the exposure process, the MQ137 sensor detected low gas levels due to its great sensitivity. However, the performance was affected by heat and humidity inside the sealed container, which can impact and cause response fluctuations before it reached a maximum voltage of 3.3 V. ZnO-2 demonstrated a more stable starting trend before gradually rising to 3.3 V, but ZnO-1 and ZnO-3 shown great sensitivity with steady voltage rises, stabilizing at row 5 (0.1 V) and row 6 (0.06 V), respectively. These findings support the capability of ZnO gas sensors to detect the gases that are released from spoiled chicken meat, where the fabricated sensor in this study can also produce high performance as a commercial sensor.

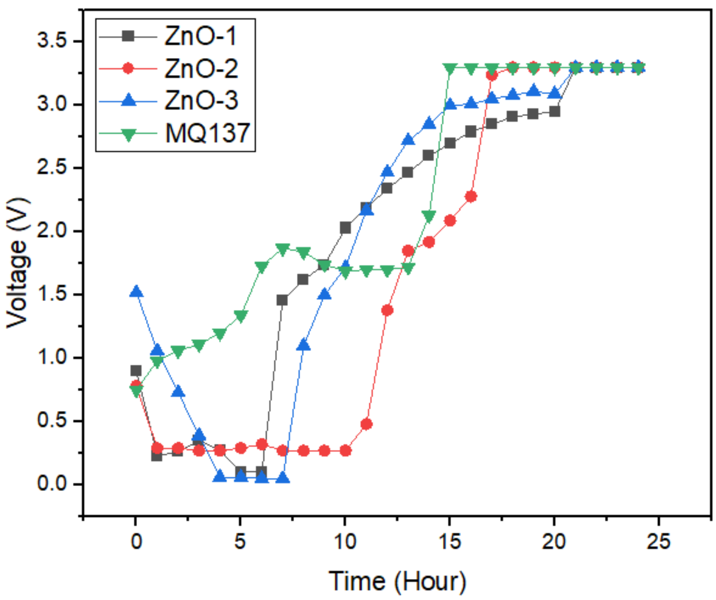

Figure 10 Comparison of the sensing response of ZnO gas sensors with MQ137 to 200 g of chicken breast

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Table 3 lists the ZnO gas sensor's sensing response values and response times compared to MQ137 exposed to 200 g of chicken breast. It can be noticed that the sensing response values for ZnO gas sensors demonstrated greater sensitivity than MQ137. The ZnO gas sensors also showed better gas adsorption capabilities, which resulted in increased sensitivity and quicker response times when detecting the released gas. Among the experimental results, the ZnO-3 gas sensor performed the best, as shown by the highest response rate. The findings support the promise of ZnO-based sensors for food spoilage monitoring applications by demonstrating how well they detect spoilage gases as compared to MQ137.

Table 3 Response value of ZnO gas sensors and MQ137

Sample name	Sensing Response	Spoiling Time (Hour)
ZnO-1	14.35	21
ZnO-2	11.38	17
ZnO-3	55.00	21
MQ137	4.40	15

Comparison with Previous Research Studies

Table 4 presents a comparison of the results produced in this study with previous studies. Most of the studies used commercial sensors in their studies. As may be observed, the ZnO gas sensors in this study demonstrated good responsiveness and reliability for detecting ammonia from chicken breast compared to other studies. On the other hand, the ZnO sensor outperformed all other sensors, with a response of 55 at 25°C for 200 g of chicken breast.

Table 4 Comparison with previous research studies

Part of Chicken	Sensing Material	Weight (g)	Type of Gas	Operating Temperature (°C)	Sensing Response	References
Fillet	MQ7, MQ8, MQ135, and MQ136	20	Ammonia	30	1.36	(Al Isyrofie et al., 2022)
-	MQ2, MQ3, MQ7, MQ8, MQ135, and MQ136	300	Ammonia	37	1.10	(Astuti et al., 2021)
Breast	MOS	25	volatile basic nitrogen	4	45	(Tang & Yu, 2020)
Breast	MOS	25	Ammonia	4	12	(Raudienė et al., 2018)
-	MOS	218	hydrogen sulphide	25	1.78	(Tayagornkul & Nimsuk, 2018)
Breast	ZnO MQ137	200	Ammonia	25	55 1.69	This study

IoT Blynk Application

Figure 11 shows the recorded voltage of the ZnO gas sensor on the breast chicken using the Blynk application. The recorded voltage was similar to the plotted graph in Figure 8, where the recorded voltage was taken in 24 hours. With features of the IoT platform, the recorded data makes it easier to monitor the sensor responses effectively while showing patterns and consistency. The real-time data can show changes in the voltage over the duration of the 24-hour test period. Tracking and data recording using Blynk software was easier for analysis; however, there were a few issues, such as connection with internet access, which sometimes affected Blynk's recording. The Blynk application can be a useful platform for real-time monitoring, especially to monitor food freshness, where this platform can also reduce the use of workers to record the data for 24 hours.

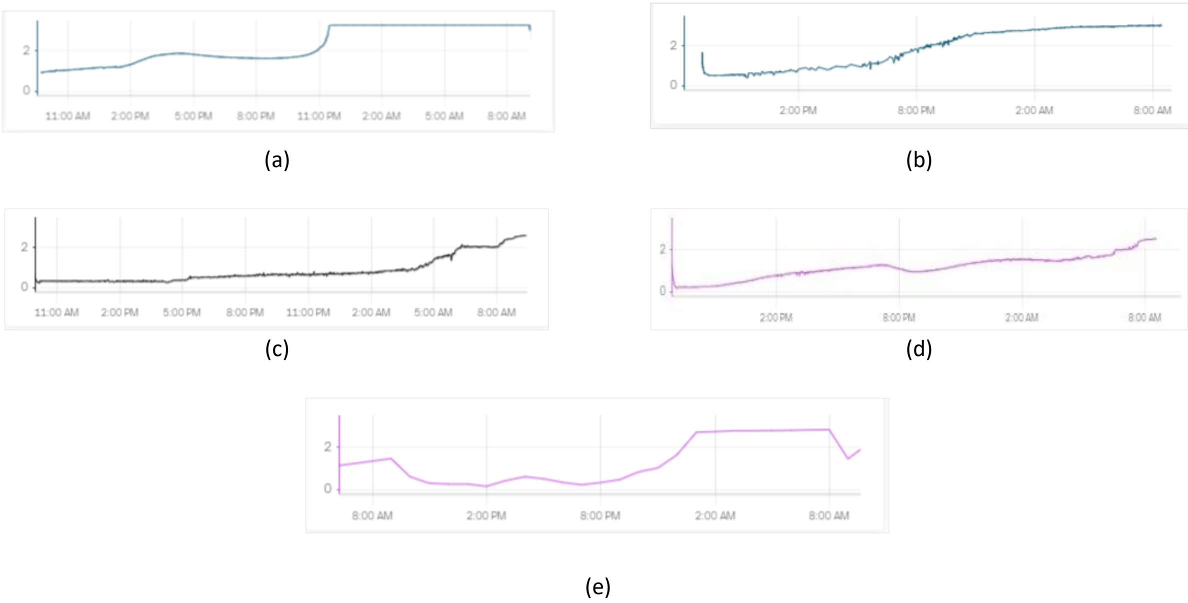

Figure 11 The recorded voltage of ZnO gas sensor via Blynk application of ZnO gas sensors for various weights of chicken breast: (a) 200 g, (b) 100 g, (c) 50 g, (d) 25 g, and (e) 10 g.

Discussion

Overall, the fabricated ZnO gas sensors proposed in this study can sense the chicken freshness by observing the variation of gas sensor voltages. It can be observed that all chicken breasts were totally spoiled in 20 hours for various chicken weights. The observed patterns in voltage responses across different weights of chicken breast exposure highlight the repeatability and sensitivity of the ZnO sensors. In alignment with n-type gas sensor behaviour, the ZnO gas sensors showed increased voltages when exposed to spoilage gases over 24 hours of expose process. Variations in initial and maximum voltages were influenced by the gas concentration and proportional to chicken weight, environmental factors example sunlight exposure and air conditioner shutdown and sensor stability over time. The findings demonstrate the ZnO sensor capability to detect gas release and suggest their potential for application in spoilage detection, with consistent response trends analogous to those reported for oxidizing gas detection by n-type sensors.

The use of this IoT system in real-time monitoring applications has been proven by the effective tracking and recording of sensor responses. With the scalability of IoT technology, this technology can be applied in food freshness monitoring and food packaging across the entire supply chain, where the data can be shared across multiple product lines. In order to become an affordable system, the IoT system can be implemented in a large-scale system and focuses on high-volume and demanding products such as meat, seafood, and dairy products. A supply chain system that is able to provide real-time visibility, predictive insights, and automated decision-making can enhance food safety, reduce waste, and increase consumer trust.

Conclusion

Fabrication of ZnO gas sensors using the screen-printing technique was successfully achieved. The resistance of fabricated ZnO gas sensors was in the range of 123.61 MΩ to 145.07 MΩ. The highest sensing response was achieved by the ZnO-3 gas sensor at 55, exposed to the 200 g chicken breast. Overall, ZnO-4, ZnO-5, and ZnO-6 gas sensors demonstrated the best performance for chicken breast, in terms of achieving stable and saturated responses over 24 hours with identical sensing response patterns, with sensing response values of 7.82, 9.83, and 13.33 for Test 1, 2, and 3, respectively. The use of the Bylnk application as an IoT platform in real-time monitoring applications has been proven by the effective tracking and recording of sensor responses.

This study can be a potential project for application in chicken meat spoilage detection, with consistent response trends. The fabricated ZnO gas sensors highlight the ability to detect spoiled chicken breast and show that it has the potential to set further standards for food quality monitoring applications, making it the most dependable option for gas sensing applications. For future research, this gas sensor can be used to detect other food frehsnness such as beef meat, fruit and etc to investigate the capability of the gas sensor in food industries.

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Compliance with ethics guidelines

The authors declare they have no conflict of interest or financial conflicts to disclose.

This article contains no studies with human or animal subjects performed by the authors.

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