

Research Article

AI-LONG: DETECTION OF FOOD SPOILAGE IN COMMON CARINDERIA DISHES USING AN ELECTRONIC NOSE SYSTEM BASED ON SUPPORT VECTOR MACHINE

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Abstract

Food safety remains a global concern, particularly because conventional approaches, such as visual inspection and sensory evaluation, have limitations in detecting food spoilage and preventing foodborne illnesses. Recent advances in sensing technology, including the E-Knows electronic-nose system, provide promising tools for real-time food-quality monitoring. This study integrated E-Knows olfactory sensors, gas sensors, pH measurements, and temperature monitoring to detect spoilage in selected foods served by PUP Lagoon concessionaires. Samples comprised coconut-milk-based, vinegar-based, and pasta dishes. Sensor responses to spoilage-related gases, including methane, hydrogen, carbon dioxide, hydrogen sulfide, and ammonia, were classified using a Support Vector Machine (SVM) model. The E-Knows system demonstrated high classification accuracy and complemented pH and temperature measurements, thereby strengthening the overall assessment of food quality. These findings may support the development of a food safety management system for PUP Lagoon food stalls and contribute to improved monitoring and food-handling practices among vendors.

1.Introduction

Foodborne diseases and spoilage are significant global health concerns, both contributing to public health risks and economic losses. According to a study, from January 2005 to September 2021 in the Philippines, there were 63 foodborne disease outbreaks (FBDOs)

affecting school-aged learners and teachers, resulting in 4,354 hospitalizations, 635 instances of home medication, and 38 deaths (Limon et al., 2022). Food spoilage, primarily caused by microbial activity, leads to changes in the appearance, taste, or smell of food. However,

not all contaminants exhibit visible signs, which makes early detection of spoilage particularly challenging (Deng et al., 2023). Effective food safety and management practices are essential in minimizing foodborne diseases and spoilage. Such practices also contribute to sustainable development by supporting global sustainability goals (SDGs 12 and 13), reducing food waste, and offering both economic and environmental benefits.

The limitations in traditional sensory evaluations have driven the development of advanced detection systems such as electronic noses (e-noses). These systems, integrated with machine learning algorithms such as Support Vector Machine (SVM), can detect food spoilage with 78.33% accuracy by monitoring gases released during microbial activity, such as hydrogen sulfide (H_2S) and ammonia (NH_3) (Yuan et al., 2020; Saini et al., 2021). This study aims to validate the results and readings of an e-nose system by analyzing a range of foods available at the Polytechnic University of the Philippines (PUP) Lagoon, including items with varying ingredients, such as pasta, vinegar-based dishes, non-vinegar dishes, and foods prepared with coconut milk (gata).

The general objective is to integrate the e-nose as a tool for assessing the safety and quality of foods sold at the Polytechnic University of the Philippines Lagoon, ultimately contributing to the development of university food safety guidelines informed by the findings of this study.

A. Food Spoilage

Food spoilage is a biochemical reaction caused by microorganisms like bacteria and fungi, which alter food's color, texture, taste, and odor. The primary factors contributing to deterioration of food quality are microbiological and chemical changes, such as protein modifications and lipid separation. Bacteria, temperature, relative humidity, and storage conditions can significantly affect the freshness of food in containers or refrigerators. While the underlying mechanisms remain unclear, sensory assessment is the primary method for spoilage detection, with advanced techniques measuring

even low contaminant concentrations (USDA, 2024).

1. Public Health Risks Associated with Food Spoilage

Food spoilage poses important public health issues, primarily due to the proliferation of harmful microorganisms that may grow when food is improperly stored or handled. Spoiled food could contain hazardous bacteria at "Danger Zone" temperatures (40°F to 140°F) where bacteria can multiply every 20 minutes and generate toxins that cause foodborne diseases (Preethichandra et al., 2022).

2. Polytechnic University of the Philippines Lagoon

The Polytechnic University of the Philippines (PUP) Lagoon, a man-made feature on campus, functions as a central location for student dining and socialization. Several food concessionaires operate within this area, offering a diverse selection of food items, such as rice meals, street foods, sandwiches, and beverages. The PUP Lagoon Food Concessionaires' operating hours, generally from 8:00 AM to 6:00 PM, align with university class schedules, allowing students easy access to affordable food options throughout the academic day.

B. Role of Gases in Food Spoilage

Gases play an important role in food spoilage, with microorganisms producing harmful gases such as hydrogen sulfide (H_2S), carbon monoxide (CO), ammonia (NH_3), methane (CH_4), and volatile organic compounds (VOCs). H_2S is released by bacteria such as *Desulfovibrio* during protein breakdown (Djenane & Roncales, 2018). On the other hand, CO is produced by clostridium species in anaerobic conditions [8], while Ammonia and VOCs, including aldehydes, contribute to the foul odors and degradation associated with spoiled food (Saini et al., 2021; Sinharoy et al., 2019).

1.1. Aldehydes

Aldehydes are organic compounds that are often found in the air and in foods. When present in excessive amounts, they contribute to undesirable smells and flavors. These

substances are related with lactic acid bacteria, *Saccharomyces*, and enterobacteria, which contributes to food spoiling (El-Maghrabey et al., 2021). Moreover, aldehydes can increase lipid oxidation, resulting in rancidity and off-flavors in food (Jung et al., 2021). It also causes color changes in food. Acetaldehyde, benzaldehyde, and hexanal are the most frequent aldehydes associated with food spoilage. With which Acetaldehyde is a highly reactive and hazardous compound found in fruits and vegetables that causes cellular and chromosomal damages (NCBI, 2024). While Benzaldehyde, a clear to yellow liquid found naturally in almonds and cherries, may produce an intolerable bitter taste when consumed excessively (Zhu et al., 2022).

1.2.Ketones

Ketones, along with other volatile organic compounds (VOCs) such as alcohols, esters, and sulfides, are common in spoiled foods and are linked to microbial spoilage metabolism (Yin et al., 2023). Bacteria break down food components, producing ketones and other byproducts, which impact food quality by altering taste, smell, and acceptability. Studies show that spoilage in apples results in VOC emissions, including ketones, detectable through gas sensors and chemometrics (Cauchie et al., 2020), and similar findings are observed in minced pork to assess decomposition and shelf life (Zhou et al., 2022). Understanding ketones' role in spoilage is crucial for improving food preservation and safety.

1.3.Alcohol and Ester

Alcohol is produced during the spoilage of various foods, including fruits and meats, with ethanol content in grapes increasing over time as a spoilage indicator (Parlapani et al., 2023). Bacteria, such as *Pseudomonas* species in spoiled fish, produce alcohols and other VOCs, correlating with advanced spoilage (Cui et al., 2022). These compounds contribute to off-flavors, odors, and health risks due to pathogenic microorganisms. Alcohol emissions are also common in food waste (Sourri et al., 2022), while ester production during microbial

fermentation further deteriorates food quality (karanth et al., 2023). Environmental factors, such as temperature, pH, and acidity, influence microbial metabolism, exacerbating spoilage (Marconkowska & Jeleń, 2022).

1.4.Sulfur Compounds

Volatile sulfur compounds are crucial in determining the odor and flavor of food. Marcinkowska and Jeleń highlight that these compounds are often responsible for specific food aromas (Chevron Phillips Chemical, n.d.). For instance, dimethyl sulfide, a methyl sulfide naturally produced by marine algae, is associated with cooked vegetables and certain seafood, resulting from the breakdown of sulfur-containing amino acids (Deng et al., 2023). Another sulfur compound, hydrogen sulfide, is produced by bacteria in anaerobic environments (Awosika & Connolly, 2023). Additionally, mercaptans, sulfur-containing compounds known for their strong and unpleasant odor, are primarily used as odorants in natural and fuel gases. These compounds can be produced by both spoilage and beneficial microorganisms (Utah State University, 2023).

C. Role of Humidity in Food Spoilage

The study of Utah State University (2023), suggested that the humidity in the storage environments such as food stalls should be at an exact or enough percentage (%), notably 50%-60% to keep the food safe (URS Testing Laboratory, 2024). Based on the study of URS Testing Laboratory (2024), Humidity is known as the silent spoiler because high humidity in soup based food and dried foods can lead to mold growth that can increase the activity of microbial organisms which leads to food spoilage (Chang et al., 2022). On the other hand, low humidity can cause the food to dry out, losing its taste and texture.

D. Role of Temperature in Food Spoilage

Temperature plays an important role in metabolic rates and growth of food-spoiling microorganisms. The chance of these microorganisms to survive are practically zero below freezing, however, the chance rises along with the temperature, as the chemical reactions that keep living things alive occur more slowly

in the cold (Bastiaan Molleman, et al., 2022). Taking into account that microorganisms require time to multiply, when small amounts of microorganisms are present, the risk is usually low, but extended time under the right conditions will enable the microorganisms to multiply, thus increasing the chance of contamination.

E. Gas Readings

The gas sensors employed in this study are designed to detect various gases, including ammonia (NH₃), hydrogen sulfide (H₂S), carbon dioxide (CO₂), methane (CH₄), and volatile organic compounds (VOCs) at specific concentrations, measured in parts per million (ppm). Ammonia (NH₃) at 4.5% gas concentration has a 0.1 to 1 ppm value in room temperature and 5 ppm at 175°C, whereas at 20% of the gas concentration has a value of 0.2 ppm or higher (Ricci & Gregory, 2021; Shen et al., 2020; Hingangavkar et al., 2023). The hydrogen sulfide (H₂S) at 0.51% gas concentration yields a 1 ppm measurement at room temperature, while at 39.19% it yields a 100 ppm reading (Shwetha et al., 2022). Carbon dioxide (CO₂) has a reading of 552 to 4751 ppm at gas concentrations less than 5%, while methane (CH₄) has a reading of 300 ppm at low concentrations and more than 300 ppm at high concentrations (Sandhya et al., 2023; Pranav et al., 2021).

2. Materials and methods

2.1. Raw Materials

2.1.1. Device Calibration

The electronic nose (e-nose) system consisted of five gas sensors: MQ-5, MQ-8, MQ-135, MQ-136, and MQ-137. These sensors were used to detect changes in volatile compounds potentially associated with food spoilage, including methane, hydrogen, carbon dioxide and other air-quality-related gases, hydrogen sulfide, and ammonia. Before data collection, the sensors were allowed to warm up and were calibrated under controlled conditions using known gas concentrations or reference values. Calibration was performed to establish the baseline response of each sensor and

improve the consistency of measurements during the experiment.

2.2. Sample Preparation

The study evaluated six common carindaria dishes grouped according to their major ingredients or preparation methods:

- Coconut milk (gata) dishes: Bicol Express and Ginataang Kalabasa
- Vinegar-based dishes: Paksiw and Pork Adobo
- Noodle dishes: Palabok and Pancit Canton with Bihon

One prepared batch of each dish was obtained from the PUP Lagoon Food Concessionaires. One sample unit was collected from each batch and placed in a designated container for e-nose monitoring. Therefore, the experiment included six food samples representing six independently prepared dishes.

Each sample was monitored once every hour for six hours, from 11:00 AM to 4:00 PM. This produced six time-point readings per food sample. With six dishes and six readings per dish, the dataset consisted of:

$$6 \text{ food samples} \times 6 \text{ hourly readings} = 36 \text{ total observations} \quad (1)$$

Each observation contained readings from the five gas sensors, together with the corresponding pH and temperature measurements. Thus, the dataset contained 180 individual gas-sensor values:

$$36 \text{ observations} \times 5 \text{ gas sensors} = 180 \text{ sensor values} \quad (2)$$

No technical or biological replicates were conducted; therefore, each hourly measurement represented one observation for each dish.

2.3. Data Collection

Data collection was conducted over a six-hour period corresponding to the operating hours of the PUP Lagoon Food Concessionaires. Measurements were obtained at six hourly time

points: 11:00 AM, 12:00 PM, 1:00 PM, 2:00 PM, 3:00 PM, and 4:00 PM.

At every time point, the e-nose system recorded the responses of the MQ-5, MQ-8, MQ-135, MQ-136, and MQ-137 sensors for each of the six food samples. A pH meter equipped with a temperature probe was also used to measure the pH and temperature of each sample. Accordingly, six observations were obtained per dish, resulting in 36 total observations.

The hourly measurements were used to monitor changes in sensor responses, pH, and temperature throughout the observation period under the environmental conditions encountered at the concessionaire site.

2.4. Data Analysis

The collected data were organized so that each observation represented one food sample at one hourly time point. The input variables for the classification model included the responses of the five gas sensors, while pH, temperature, observation time, and food type were recorded as supporting variables.

Before model development, the sensor data were checked for incomplete or invalid measurements and normalized to minimize differences in scale among the sensors. A Support Vector Machine (SVM) algorithm was then used to classify the spoilage condition of the food samples.

The dataset consisted of 36 observations derived from six dishes measured at six hourly time points. The procedure used to divide the observations into training and testing datasets was documented to ensure that model performance could be reproduced. The resulting SVM classification was compared with the reference spoilage classifications established through pH measurements, temperature measurements, sensory evaluation, and visual inspection. Relationships between sensor responses, pH, and temperature were also examined. The SVM model achieved an overall classification accuracy of 78.33%

2.5. Validation

The classification performance of the SVM model was evaluated using accuracy, precision, recall, and F1 score. A confusion matrix was also generated to show the number of correctly and incorrectly classified observations for each spoilage category.

The classifications generated by the e-nose system were compared with the reference assessments obtained through pH and temperature measurements, sensory evaluation, and visual inspection. In addition to classification performance, the operational quality of the developed system was evaluated based on selected ISO/IEC 25010 characteristics, including reliability, portability, and maintainability.

Because the dataset contained only 36 observations from one batch per dish without independent replicates, the reported accuracy should be interpreted as preliminary. Additional batches and independent replicates are recommended to evaluate the model's generalizability and reliability under varying preparation and storage conditions.

3. Results and Discussion

3.1. Device and Tools

The instruments used in the study were the AI-Long electronic nose (e-nose) prototype and a digital pH meter equipped with a temperature sensor.

The AI-Long device is an e-nose system designed to detect volatile compounds associated with food spoilage. It integrates multiple gas sensors with a Support Vector Machine (SVM) algorithm to classify the spoilage levels of the selected food samples. The prototype was originally developed during the initial phase of the AI-Long research project and was subsequently used in the present study for data collection and spoilage classification.



Figure 1. Actual Device Prototype

A digital pH meter with an integrated temperature sensor was also used to measure the pH and temperature of each food sample. The pH measurements provided information on changes in acidity or alkalinity that may occur during spoilage, while the temperature measurements were used to monitor the thermal condition of the samples during the observation period. Because pH readings can be affected by temperature, the integrated temperature sensor supported more accurate interpretation and, where applicable, temperature compensation of the pH measurements. Both pH and temperature values were recorded alongside the e-nose sensor readings at each hourly sampling point.

3.2. Data Set

The dataset was collected using the E-Knows electronic nose system, which consists of an array of five MQ gas sensors: MQ-5, MQ-8, MQ-135, MQ-136, and MQ-137. A digital pH meter with an integrated temperature sensor was also used to record the pH and temperature of each food sample. The E-Knows device was programmed to collect gas-sensor readings at two-hour intervals.

Six dishes commonly served in carinderias were included in the study. These were grouped according to their primary characteristics:

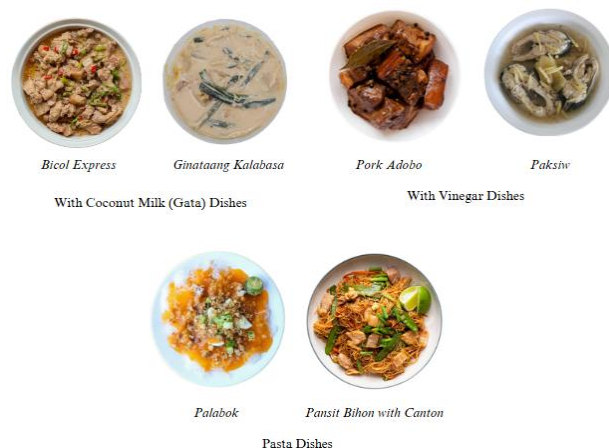


Figure 2. Data Set for Food Testing

At each testing interval, the readings from the five gas sensors were recorded together with the corresponding pH and temperature measurements. These measurements were used as input variables for analyzing changes associated with food spoilage.

Paksiw and Pork Adobo were classified as vinegar-based dishes because vinegar is a major ingredient in their preparation. The E-Knows device was used to evaluate the condition of the samples by detecting changes in the volatile compounds they emitted. The readings from the MQ gas-sensor array were processed using a Support Vector Machine (SVM) algorithm, which classified the samples according to their spoilage condition.

For the Paksiw sample, Tests 1–3 were classified as “good,” whereas Tests 4–6 were classified as “spoiled.” These findings indicate that the pattern of volatile compounds changed as the observation period progressed.

Although pH can provide useful information about food quality, it should not be treated as a definitive indicator of spoilage. Paksiw and Pork Adobo are naturally acidic because they contain vinegar. Their initially low pH values may therefore reflect the dishes’ ingredients rather than their spoilage condition. Moreover, acidity may inhibit some microorganisms without preventing all forms of microbial growth or chemical deterioration. Consequently, pH measurements alone may not

reliably distinguish good samples from spoiled ones in vinegar-based dishes.

The E-Knows system provided an additional basis for assessment by analyzing the combined responses of the gas sensors. However, its results should be described as complementary to the pH and temperature measurements rather than inherently more accurate unless this is demonstrated through comparison with an established reference method, such as microbial analysis.

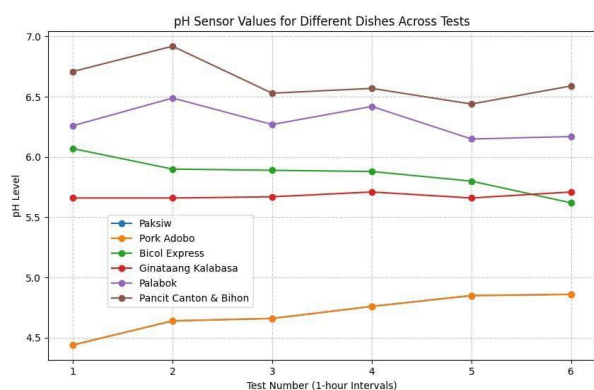


Figure 3. pH Meter Result

The samples were maintained at approximately 30–31 °C during testing. This temperature should not be described as a safe storage range because it falls within the temperature danger zone in which many foodborne microorganisms can multiply rapidly. Prolonged exposure to these conditions may therefore accelerate microbial activity and food deterioration.

The two-hour guideline provides a practical food-safety reference for potentially hazardous foods kept at room temperature. Nevertheless, the exact rate of spoilage may differ among dishes because of variations in ingredients, moisture, acidity, preparation methods, initial microbial load, and environmental exposure. Temperature measurements were therefore used to document the samples' storage conditions and support the interpretation of the e-nose and pH results.

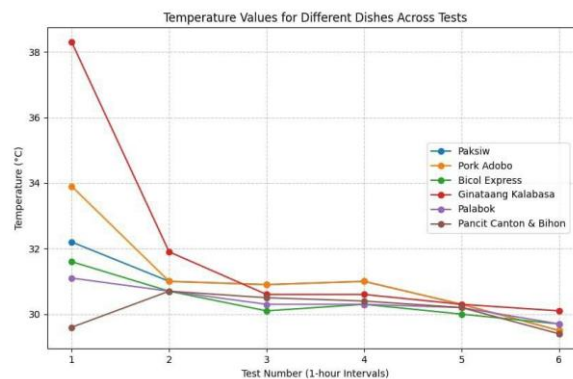


Figure 4. Temperature Result

The relationships among pH, temperature, and the E-Knows classifications were not consistent across all dishes. This result suggests that food spoilage cannot be reliably evaluated using a single indicator. Instead, the combined effects of storage time, temperature, acidity, ingredients, and volatile-compound production should be considered.

For Bicol Express, the pH remained within the expected range during some testing intervals even though the E-Knows system classified the sample as spoiled. This disagreement suggests that changes in volatile compounds may occur without a substantial change in pH. The dish's ingredients and the specific microorganisms or chemical reactions involved in deterioration may also have influenced the results.

For Ginataang Kalabasa, changes in pH occurred alongside classifications of spoilage by the E-Knows system. Because the sample was also exposed to approximately 30–31 °C, temperature and storage duration may have contributed to its deterioration. However, without microbial testing or another reference method, the individual effects of pH, temperature, and time cannot be conclusively determined.

For Palabok and Pancit Canton with Bihon, the E-Knows system identified changes associated with spoilage. These classifications were accompanied by increased responses from several gas sensors, particularly MQ-5, MQ-8, and MQ-135. This finding suggests that these sensors responded to changes in the mixtures of volatile compounds emitted as the noodle dishes deteriorated. However, the individual

compounds responsible for the responses were not identified.

Temperature and testing duration should also be considered when interpreting these findings. Because the samples were exposed to room temperatures of approximately 30–31 °C and tested at two-hour intervals, elapsed time may have influenced both volatile-compound production and the resulting SVM classifications. The findings demonstrate the potential of an MQ sensor-based electronic nose for supporting food-quality assessment. Further research involving larger datasets, independent sample replicates, microbial analysis, sensor calibration, and controlled storage conditions is needed to determine the system's sensitivity, specificity, and reliability.

3.3. Device Performance

The temperature sensor and pH meter were placed on the same device. In the food testing, foods with vinegar such as paksiw and pork adobo showed a slight increase in their pH over the time of testing. The food with coconut milk such as bicol express and ginataang kalabasa developed a slightly sour odor and discoloration over the testing period. The food with pasta such as palabok and pancit canton with bihon showed an increased pH and developed an off odor over the testing period. This result from pH meters was also caused by the temperature. Temperature can alter the reactions and build up microorganisms inside the food.

In correlation of the pH meters and temperature to the MQ gas sensors (MQ-5, MQ-8, MQ-135, MQ-136, and MQ-137) result. Gas sensors detect the emitted gasses that the spoiled food releases. Temperature with a high result can accelerate microbial growth, leading to increased VOC production and faster food spoilage. In general, higher temperatures can lead to higher gas sensor readings, as increased microbial activity that alters the pH results in greater VOC emission.

Fig. 5-10 indicates the result for gas sensors (MQ-5, MQ-8, MQ-135, MQ-136, and MQ-137). This graph shows that the first 3 testing commonly resulted to a good food quality and

the last 3 (4-6) testing commonly result to a spoiled food quality.

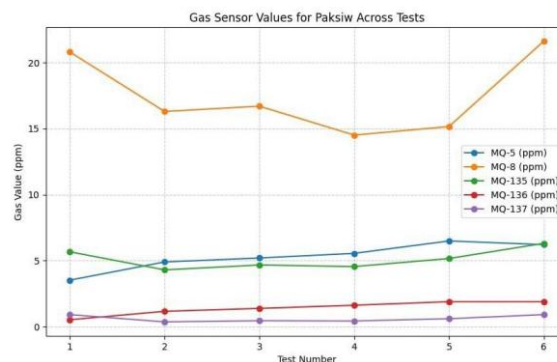


Figure 5. Gas Sensor Values Paksiw

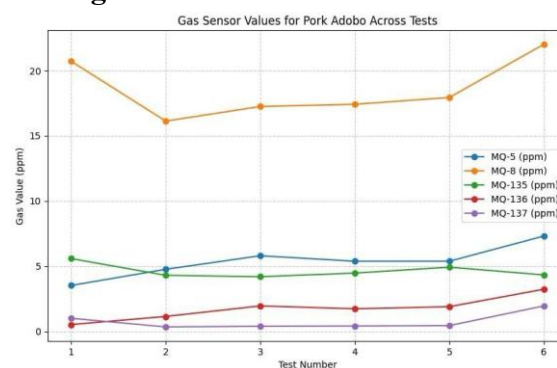


Figure 6. Gas Sensor Values Pork Adobo

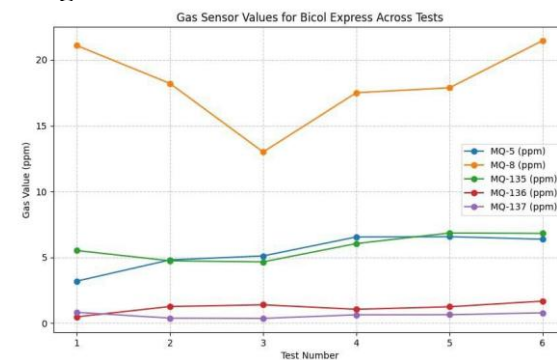


Figure 7. Gas Sensor Values Bicol Express

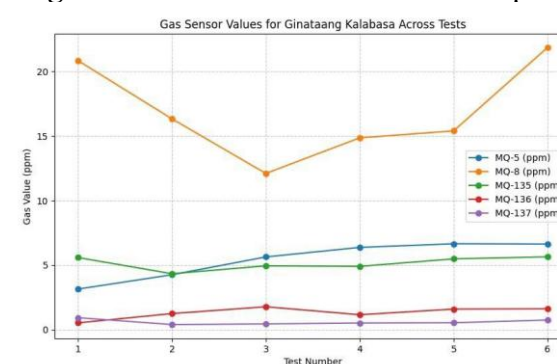


Figure 8. Gas Sensor Values Ginataang Kalabasa

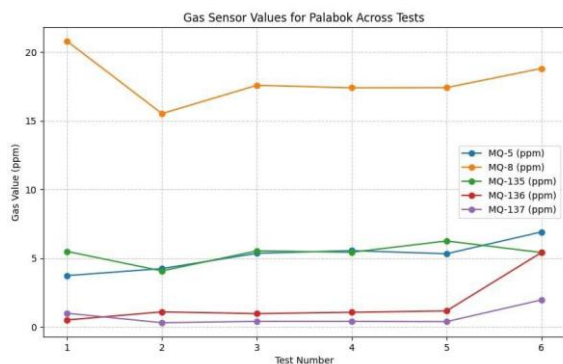


Figure 9. Gas Sensor Values Palabok

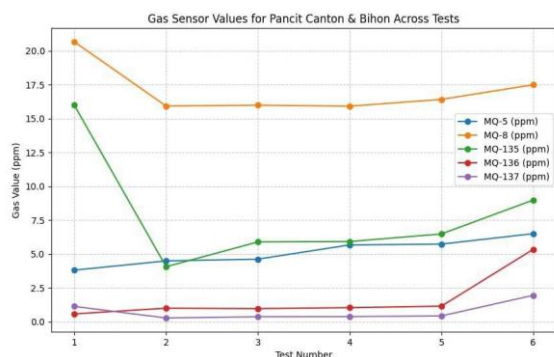


Figure 10. Gas Sensor Values Pancit Canton & Bihon

4. Conclusions

In conclusion, this study demonstrates the potential of integrating electronic-nose technology with pH and temperature measurements to assess food spoilage. The E-Knows sensor array provided useful information on changes in the volatile compounds emitted by different food categories, including vinegar-based dishes, coconut-milk-based dishes, and pasta dishes. Its results suggest that olfactory sensor data can complement conventional measurements when evaluating food quality.

The pH measurements were less indicative of spoilage in acidic foods such as Paksiw and Pork Adobo because their vinegar content maintained an acidic environment that may have obscured spoilage-related changes. In contrast, variations in the pH of Ginataang Kalabasa showed a clearer association with the spoilage classifications generated by the system. These findings indicate that pH should not be used as the sole basis for determining food quality.

Temperature was also an important factor. Samples stored at approximately 30–31 °C were exposed to conditions favorable to microbial

growth and food deterioration. Longer exposure at these temperatures was generally associated with changes in pH, increased gas-sensor responses, and spoilage classifications from the E-Knows system. This finding emphasizes the importance of proper temperature control and limited holding times in reducing food-safety risks.

The MQ-5, MQ-8, MQ-135, MQ-136, and MQ-137 sensors successfully detected changes in gas-response patterns associated with the volatile compounds released during food deterioration. When these responses were evaluated together with pH, temperature, and storage duration, the system provided a more comprehensive assessment than any single measurement alone.

Overall, the findings indicate that the AI-Long prototype, incorporating the E-Knows electronic-nose system, has potential as a supplementary component of a food-safety monitoring system for the food stalls at the PUP Lagoon. However, further testing using a larger and more diverse dataset is necessary. Future studies should compare the system's classifications with microbiological and chemical laboratory analyses, calibrate the sensors under controlled conditions, and evaluate the prototype in actual food-service environments before it is used for operational food-safety decisions.

Recommendation

While this study showed a promising result, based on the findings, the following recommendations are proposed:

1. Conduct study on the microbial growth of carindaria dishes counterpart to further enhance the concept of AI-Long
2. Consider combining the AI-Long with other sensors such as colorimeter and moisture level of the food to create a more comprehensive and reliable food quality monitoring system.

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