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THE POTENTIAL OF ELECTRONIC NOSES IN QUALITY AND FRESHNESS PREDICTION OF FRESH AND STORED MEAT PRODUCTS

Review

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Abstract: *The present review aimed at evaluating the potential of e-noses in real-time quality and freshness monitoring and evaluation of a variety of fresh meat products (Beef, Pork, Chicken and Fish) in view of their inherent differences. Electronic noses (e-noses) have been demonstrated to have great potential in food quality monitoring and prediction. Several experimental trials on e-noses have been conducted to assess their ability in quality screening of food products. In this review, the success and shortcomings of the e-nose performances are discussed including the previous and current advancement. A narrative literature review approach was used to critically evaluate literature which waz summarized with conclusions drawn and the inconsistence / drawbacks in the functionality of e-noses in quality monitoring revealed.*

Key words: *E-noses, food quality screening, meat products*

1. Introduction

Meat and fish are among the highly perishable foods with a very short shelf life especially when handled inappropriately. Poor handling subjects these perishable food items to accelerated spoilage. Semeano [1] indicated that fish products are exceedingly perishable and sensitive to microbial growth, and the risks linked with the consumption of food contaminated with harmful bacteria are considerable. According to Chamhuri and Batt [2] food quality is usually related to freshness, food safety and nutritional value. Other researchers [3] reported that once the quality of food is lessened because of the low level of freshness, purity factor, safety and nutrition, it can contribute to health risks. Proper monitoring of quality is therefore an important element in ensuring food quality and safety of consumers and it is even more critical when dealing with highly perishable food materials. The situation can even be further aggravated due to improper handling during transport, selling or storage.

Conventional quality control methods are available which include microbiological and physical or chemical techniques. Although efficient and accurate, these methods have some common shortcomings, such as high costs of execution, extended time of analysis, low samples throughput, dependence on greatly qualified labor force, inapplicability for online production monitoring [4] and destructiveness of investigated products [5]. On the other hand, Zhang *et al.* [6] described end-results of sensory analysis, an alternative method to rely on individual's skills; as such it is prone to frequent errors. Other major drawbacks of this method are the elevated cost of training the human panel, low degree of reproducibility of evaluation, and standardization of the measurement [5]. Falasconi *et al.* [4] documented several chemical methods for examining meat quality such as Total Volatile Basic Nitrogen (TVBN), pH, Triphenyl Tetrazolium Chloride (TTC), and test paper which also require extended time, are expensive with inadequate precision [6]. Due to their compositional nature, meat and fish can quite easily (especially in case of poor handling) reach a spoilage point. According to Benabdellah *et al.* [7] the point of spoilage is described by the upper limit of acceptable bacterial level, undesirable odor or aspects for consumption. The familiar characteristics associated with spoilage are foul odor and gas production [7]. In view of the challenges associated with the conventional methods and a very short shelf life of meat products, researchers have attempted to develop quick simple alternatives, easy to use non-destructive devices for real-time monitoring and evaluation of food freshness and quality. These attempts include mimicking the human nose system to identify spoiled products based on their odor [5] that is an electronic nose (e-nose). E-nose, a device performing odor analysis takes its name from the human nose, and the process is known as machine olfaction [5]. The chemical and biosensor technologies have emerged as valuable contenders for food quality control due to their simplicity of use, low cost, rapidity, and good correlation with sensory panels [4]. E-noses rely on an array of semi selective gas sensors and a suitable data processing method (pattern classification algorithm/ technique) [4, 5, 8] capable of measuring and identifying volatiles which contribute to specific odors [5, 8]. E-noses are advocated to present rapid and accurate way of sensing the incidence of food contaminant bacteria with minimal or no sample preparation [4]. Therefore, this present review paper aims to bring to light an overview of current results achieved by applying e-noses in quality evaluation, highlighting their success, strength and drawbacks, scope of use and their potential in quality monitoring of meat products with great inherent differences.

2. Description of Meat Products and E-nose

2. 1 Fish freshness parameters

Generally, fish freshness quickly degrades due to enzymatic decomposition of adenosine triphosphate after death. Gradually, reductive gaseous species which are the main components of the odour resulting from fish decay such as volatile sulfur compounds, volatile acidic compounds, volatile carbonyl compounds and volatile basic nitrogen compounds are released during the decomposition of fish. Dimethylamine (DMA) and Trimethylamine (TMA) are some of the representative odours which are produced during fish decomposition [9].
Ólafsdóttir [10] on the other hand described the characteristic odour changes due to the formation of volatile compounds, like alcohols, aldehydes, ketones, esters, sulfur compounds and amines, by specific spoilage organisms (SSO) as key determinants of chilled fish quality.

2.2 Meat freshness parameters

According to Rivai *et al.* [11] aroma, color, texture and taste can be used to identify the freshness level of meat. The freshness and quality of slaughtered chicken meat depend on complex processes which are associated with different factors including

the bacteria present on the carcass prior to slaughter, the efficiency of processing, and the conditions and time of storage, which permit propagation prior to consumption and enzyme reactions [12].
The taste quality of meat is affected by volatile organic compound (VOC) content. Aroma or smell of meat is produced by complex mixture of VOC coming from a diverse chemical reaction in meat. The modern categorization of meat freshness is based on the total amount of volatile basic nitrogen (TVB-N) found in meat. TVB-N is the quantity of nitrite material that is purified from vapor or gas in meat under alkalization conditions. TVB-N includes all the nitrogen content that can form ammonia under these conditions. On the basis of TVB-N, fresh meat is defined as meat containing TVB-N lesser than 15 mg / 100 g of meat. Semi fresh meat has TVB-N between 15-30 mg / 100g of meat, and altered bacon may contain over 30 mg / 100 g of meat [11].

2.3 Meat Decomposition Products

Meat is composed of water, protein, fat, and some carbohydrates; enzymes and bacteria will decompose some meat components into volatile gases. The protein will decompose into ammonia, hydrogen sulfide, and ethanethiol; fat decomposes into aldehydes and aldehyde acid; and carbohydrate decomposes into alcohol, ketone and carboxylic acid. In the process of spoilage, these gases' concentrations will increase exponentially [13].

2.4 General description of e-nose

An e-nose is an analytical instrument designed to act-like human nose [11]. It is used for sensing food freshness by examining gaseous properties [14]. It consists of an array of chemical sensors matched with an appropriate data processing technique, capable of measuring and recognising volatile compounds which contribute to odours [8]. The configuration of an e-nose mimics the human sense of smell, learning the functions of evaluating, recognizing and identifying volatile chemicals to a higher accuracy [6]. Human olfaction relies on the chemical interaction of volatile odour compounds and neurons in the nasal cavity. The signals generated by neurons are conveyed to the brain for further recognition of a specific substance. In machine olfaction, the sensors are comparable to human neurons and the pattern-matching algorithm is similar to the brain's recognition process [5]. The e-nose technology is founded on the absorption and desorption of volatile chemicals onto a matrix of sensors [6]. The two major parts of an e-nose are the sensing system and the pattern recognition system. Sensing systems may consist of arrays or chain of diverse sensing elements (e.g. chemical sensors), in which every sensing element measures the different properties of the chemicals tested [11]. Unlike gas sensors which use specific sensors for measuring single attributes and quality and safety in the food and beverage sector, information can be also obtained from arrays of non-specific sensors with partly overlapping selectivity and treating the data obtained with pattern recognition software [15]. An e-nose is a substitute to single gas sensors which characterize complex mixtures that are more suitably recognized by an overall fingerprint rather than by the individual identification of their constituents [15]. These sensors show physical and chemical interactions with the chemical compounds when they flow over or are in contact with the sensors [14]. The response of a sensor is usually measured as the change of some physical parameters, e.g. conductivity or current [8] or change of electrical resistance once they get in touch with gas with the varied odors and aromas [6]. The responses of all sensors form a response pattern that can be learned by a computer [8]. E-nose technology is particularly of use as a speedy measurement technique for food which has been kept for an extended time and gases may present risk to the human olfactory cells [6]. The distinguishing flavor of volatile compounds, namely finger-print, may offer information about safety and specific characteristics of food. A number of volatile compounds can originate from biochemical processes of food, as a result of technological treatments or product age / storage. Undesirable smells (off-flavours) may comprise of substances originating from the metabolism of spoilage microorganisms, bacteria and fungi, which may naturally or accidentally contaminate the products before or during its production [4].

2.5 E-nose sensors working principle

The design of an e-nose includes the design of a matrix of chemical sensors, for example, gas sensors and development of a pattern-recognition algorithm. The sensor matrix sniffs the vapor from a sample and provides a set of measurements; the pattern-recognizer compares the pattern of measurements with the stored patterns of known materials. Gas sensors tend to have very broad selectivity, responding to many different substances. This, in fact, it is a disadvantage in most applications, but it is a definite advantage in e-nose. Each sensor in a matrix may respond to a given chemical and these responses will be different [6].

Fig. 1 shows the sketch of an e-nose system with several sensors arranged in a cabin and constructed into a sensor matrix. Flavor is detected by the sensor matrix and electric signals are generated. Signals are filtered and amplified by an Adjustment Circuit Board (ACB), and converted from analog to digital signals by A/D transfer card and the digital signals are analyzed by a computer [6].

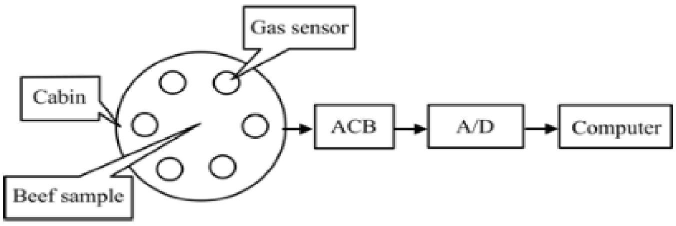

Fig. 1: Electronic nose system (adopted from Zhang et al., 2008)

2.6 Types of gas sensors

There are several types of gas sensors that have been developed which are currently available. Gas sensors are distinguished on the basis of their materials or forming materials [11] such as metal oxide semiconductor (MOS), conducting polymer (CP), metal oxide semiconductor field effect transistor (MOSFET), and piezoelectric sensors [5, 11]. In gas sensing, two kinds of piezoelectric sensors are utilized, the Surface Acoustic Wave (SAW) device and the Quartz Crystal Microbalance (BAW) [14]. MOS type gas sensor is one type of sensors that is most widely used to build e-nose systems. This is due to high sensitivity and relatively cheap price [11].

2.6 Application of e-noses in a variety of fields

E-noses have been applied in various food domains including food quality control [7], process monitoring, food freshness evaluation, shelf-life assessment, authenticity determination [5], product traceability [8], quality estimation of ground meat, beer production, prediction of the degree of musty odor in cereal and many more [3]. It is also used to classify the quality of stored grain, analysis of water and wastewater, screen roasting process, detect and diagnose pulmonary infections (e.g., pneumonia) and ulcers through breath tests, test freshness of fish and fruit, control the manufacture of cheese, sausage, beer and bread, detect bacterial growth in meat and vegetables [6]. The largest market for e-nose however, is the food industry particularly for quality monitoring or grading of food, beverage and fruits, inspection of food packaging materials [8]. Other documented applications are reflected in medicine, agriculture, environment, perfumes, drinks [7] diagnosing disease, water quality, air pollution as well as liquid chemical concentration [3] and many more [15].

3. Review and discussion of e-nose experimental trials in meat products

As indicated earlier, e-noses have wide applications in several industries, however, in the present review the focus is confined on the experimental results of e-nose performance in quality evaluation of fish and meat products (beef, pork, chicken and fish). Several studies have been made to evaluate its (e-nose) applicability in quality evaluation. Li [8] used a FreshSense e-nose with an array of four electrochemical gas sensors (CO, H_2S, SO_2 and NH_3) to evaluate the freshness of redfish (*Sebastes marinus*) maintained in ice and modified atmosphere packaging (MAP). The results of e-nose measurements were compared with the results of sensory evaluation (QI scores). The results indicated different responses and selectivity to the volatile compounds tested (both in standard compounds and red fish storage experiment). The CO sensor was the only sensor that responded to ethanol, while TMA was the only one detected by the NH_3 sensor. The SO_2 was only sensitive to dimethyl disulfide (DMDS). The results also showed that both CO and H_2S sensors responded to acetaldehyde and all the sensors responded to DMDS. The CO sensor was more sensitive to acetaldehyde than to ethanol. All the sensors were more sensitive to DMDS aqueous solution than any other compounds and DMDS in oil. They related the sensors' sensitivities to DMDS insolubility in water which accounts to its much higher concentrations above the aqueous phase than the oil phase. This implies that the solubility of volatiles compounds may affect the head space concentrations of volatile compounds and hence the sensitivity of some gas sensors. Solubility dilutes the concentration so that it reduces the sensor sensitivity. Other researchers [19] similarly reported the possibility of solubility of odorant to affect the sensitivity of the sensor since insolubility increases head space concentration of the odorant. The variation in solubility characteristics among volatile compounds emanating from different sources could thus have an implication on the functionality of the sensors. The higher sensitivity of CO sensor to acetaldehyde than that of ethanol at same concentrations was attributed to the lower boiling point of acetaldehyde than ethanol which implies its higher vapour pressure in the headspace. It was also documented that the minimum concentration the sensor can measure depends on the nature of the odorant. According to available information [20] the composition of volatile compounds in the end product is affected by different factors: breed, sex, diet and age of an animal; conditions and process of slaughter; duration and conditions of meat storage; type of muscle; preparation of meat and type of additives applied as well as conditions of heat treatment (cooking, roasting, smoking). In the red fish storage experiment [8], the CO sensor showed the highest response among sensors for all the samples stored under various conditions (ice, ice-MAP and MAP-ice).

A slower spoilage rate reflected by lower intensities of sensors' response was observed in MAP stored red fish compared with other storage conditions. The FreshSense measurements were generally in agreement with the results of sensory evaluation (QI scores). The conclusion was that the sensors showed good selectivity, sensitivity and repeatability to standard compounds that are representative of spoilage compounds in fish [8]. His results are supported by Ólafsdóttir [10] who in exploring the potential of e-nose (equipped with CO, NH_3, H_2S and SO_2 sensors) in quality evaluation of different species of fish and fish products (capelin, cod, haddock, red fish and cold smoked salmon) documented the sensors selective responses to characteristic odours emanating from volatile compounds. CO sensor was responsive of the formation of alcohols, aldehydes and esters whereas NH_3, H_2S and SO_2 sensors were sensitive to amines and sulfur compounds. The discrimination demonstrated by gas sensors [8] on the four standard compounds that are representative of spoilage compounds in fish (TMA, ethanol and acetaldehyde, DMDS) implies the dependence on the functionality of gas sensors (in terms of selectivity and sensitivity) on the aroma / odour compositions of volatile compounds.

More gas sensors means that the portability of e-nose is reduced. Comparable results were reported by other researchers [6] who demonstrated varied responses of dissimilar sensors to different gases, implying that each sensor has different output voltages for each gas. An integration of several sensors into a matrix could thus widen the scope of detection and selectivity of the system at the expense of an error inherent in a single sensor. Although this is advantageous as it broadens the gas sensors selectivity, thus responding to several different substances, it may also affect its ability to discriminate the pattern of volatiles compounds due to their overlap.

Another study [6] determined freshness of beef by using six MOS sensors based on various gases volatilized from beef stored at 20°C and relative humidity of 60% for days varying from 1 to 6. The results of beef freshness were evaluated by sensor measurement and confirmed by sensory evaluation. The results showed that dissimilar sensors can respond to different gases, implying that each sensor has different output voltages for each gas. The odor of beef originates from a mixture of gas compounds. The results demonstrated an increase in the output voltages of sensors with the stored time of beef sample, except for one sensor (Taguchi Gas Sensor, TGS2442) which reflected its inability to evaluate beef freshness. It was concluded that a few sensors have no reaction to fresh beef but have extreme reaction to decomposed beef.

However, a sensor matrix constructed from sensors that react differently to beef freshness could enhance reliability and sensitivity of detection due to their sensitivity to different gases. On the other hand, the inability of certain sensors (TGS2442) to evaluate fish freshness quality in either fresh or spoiled form [6] indicates insensitivity of some sensors regardless of the age of the food or storage duration. This can further be explained by the existing data [10] which demonstrated the responsiveness of CO sensor to the formation of alcohols, aldehydes and esters and the responsiveness of NH_3, H_2S and SO_2 sensors to amines and sulfur compounds. This suggests that the functionality of gas sensors in quality prediction may also depend on odour source, type and composition of the emanating odours. The odour of food items is based on a mix of several volatile / gas compounds, the use of an array of gas sensors (as opposed to a single gas sensor) can enhance its effectiveness and performance. This can be achieved by widening the scope of reaction through exploiting and integrating the capability of each gas sensor into a single working unit. It has also been observed that [6] some sensors are inactive / have no reaction to fresh beef but they have extreme reaction to the decomposed beef. This indicates the reliance of some sensors on the concentration of odorous compounds which increases with storage and decomposition level. This suggests early stages of spoilage might not be recognized though it is not always the case. Therefore, a proper selection of suitable and appropriate gas sensors could help in reducing or alleviating such shortcomings.

An extra experimental trial [7] was done to detect spoiled meat and its degradation level using an e-nose equipped with five MOS gas sensors (TGS and MQ) and humidity and temperature sensor (DHT11). MQ stands for Mĭngăn Qǐ lai (in Chinese) which means sensitive to gas. Durations and gases given off by decayed meat were determined by PCA (Principal Components Analysis) for classification and DFA (Discriminate Factorial Analysis) for dating and for the identification of unknown sample. The temporal response of the sensor array in the presence of two types of beef samples during 11 days showed the detection of various organic solvent vapours by different sensors and concluded that the output voltage of each sensor increased between the third and fifth day. Classification by PCA method indicated three well separated groups namely chicken free, chicken about to rot and rotten chicken. The identification results by DFA method indicated defined separation of three groups, with distinct grouping of classes around their centers of gravity with 82.29.5% success of classification. The results also showed the possibility of identification between two types (beef and chicken) that are nearly of the same odor at rottenness by DFA technique with a percentage of 78.88%. Another separate study [16] examined the freshness of beef and poultry slices, and plaice and salmon fillets using a handy and simplified e-nose system called Mastersense equipped with four MOS sensors. The sample' freshness was examined based on Total Viable Count and the results were used to categorize freshness to develop grouping models by the K-Nearest Neighbours'algorithm and Partial Least Square Discriminant Analysis. Both established models showed sensitivity and specificity with estimation greater than 83.3% and 84.0%, respectively. The comparison of the prediction ability of the two classification algorithms using McNemar's test, gave comparable values. Based on the results, it was concluded that the Mastersense e-nose system operating with the K-Nearest Neighbours' model provides the most suitable freshness assessment of meat and fish [16]. Other researchers [21] identified extended settling time of some sensors as a potential drawback particularly of methods that rely on sensors to achieve a steady state which is a disadvantage for applications needing a fast response. However, the same researchers [21] further indicated that the shortcoming can be avoided by using a fast classification algorithm that does not rely on the sensors to attain a steady state, but it rather depends on transient information from the response characteristic of the sensor once exposed to an analyte. This could possibly explain the results reported by other researchers, too [16].

Another study [9] used a multiple sensor system consisting of an oxidation-reduction (ORF) gas sensor, a hydrogen sulfide (HS) gas electrode and an ammonia (NH_3) gas electrode to measure the gaseous species released, that is, DMA and TMA which are produced during fish decomposition. The response of sensor system to odors of salmon and sardine was also determined during fish decay and compared with a sensory evaluation. The results showed a lack of response by HS sensor to DMA and TMA, but the ORF-sensor and NH_3 sensor were effective for the detection of volatile basic nitrogen compounds, which constitute one of the odour materials released during fish decomposition. The potential change for ORF-sensor and NH_3 sensor corresponded to the difference in odour concentration. The results reflected the effectiveness of the two sensors in detecting volatile basic nitrogen compounds, which form one of the odour materials released during fish decay. The reliability assessment results of the system against sensory evaluation based on salmon fish, indicated that eight participants assessed one day sample as having undergone putrefaction which coincided with the NH_3 sensor response. This suggests that the NH_3 sensor can efficiently determine salmon condition.

In the second day, all panelists declared alteration of salmon sample.

For sardine, all ten panelists declared one day sample as unaltered.

However, in the second day, only seven panelists declared the sample as unaltered. But after two and half days all the participants declared the sample altered.

During this storage experiment all sensors registered, small electric potential changes up to the second day.

For the ORF-sensor, increase in electric potential was registered in the two and a half day sample.

After the third day, a gradual increase in potential changes was registered for all sensors. The results generally indicated that sensory test corresponded well with potential changes of sensors. The reliability assessment using colony count results was evaluated based on bacterial counts N fish meat; that is, freshness N = 10^7 cells/g which is commonly defined as a stage of putrefaction. When the judgment by the sensory test panel was "no putrefaction", the sample N was about10^4 cells/g.

The N of samples, declared as putrefied by the sensory test, was about 10^{5} - 10^7cells/g, N = 10^7 cells/g which is commonly defined as a stage of putrefaction. On the basis of the colony count results, it was concluded that the validity of the sensory evaluation was objectively assessed and the potentiometric gas sensor system is efficient for fish freshness estimation. Responsiveness of the HS sensor to DMA and TMA and the responsiveness of the OR-sensor and NH_3 sensor to volatile basic nitrogen compounds, released during fish decomposition demonstrate that dissimilar sensing elements measures dissimilar properties of the chemicals measured as such any chemical or gaseous vapor exposed to a sequence of sensors will generate a pattern distinctive of the gas [11].

The other study [5] used a MOS based e-nose to measure the smell signature in two meat foods (beef and fish) stored at room temperature and identified the decayed products. They separated the samples into two groups: fresh beef with decayed fish and fresh fish with decayed beef. In addition, they tested the e-nose using three pattern classification algorithms including artificial neural network (ANN), support vector machine (SVM) and k-nearest neighbor (KNN)), and evaluated them on the basis of accuracy, sensitivity and specificity. The gas array sensor used consisted of eight MOS sensors. Their experimental results for the rotten beef with fresh fish demonstrated that out of 684 samples, the system correctly categorized 670 (ANN), 639 (SVM), and 639 (KNN) samples as rotten beef and incorrectly identified 156 (ANN), 20 (SVM), and 0 (KNN) rotten beef samples as fresh beef. As a result, ANN had the uppermost sensitivity of 97.2% but the lowest specificity of 69.59% whereas KNN had the highest specificity of 100% and a reasonable sensitivity of 93.42%. Similarly, for the rotten fish with fresh beef group, KNN did significantly better than ANN and SVM. Additionally, the accuracy rate was 85% for ANN, 94.5% for SVM, and 96.2% for KNN, which indicated that KNN algorithm has the highest performance accuracy. The results generally showed that KNN is a more reliable technique than SVM or ANN due to its relatively higher values of sensitivity and specificity for both kinds of samples. Furthermore, KNN had the uppermost accuracy rate which is a sign that it has the highest performance. It was thus identified as the most suitable pattern classification algorithm (PCA). On the other hand, the three dimensions projection of the PCA results clarified almost 95% of the variation in the data, 61.61% for PCA1, 25.55% for PCA2 and 7.3% for PCA3. They concluded that the proposed e-nose system is a very efficient tool for food inspections. The variations in sensitivity, specificity and accuracy of the PCA in recognizing the alterations in these meat products implies that the efficiency of the e-nose system is influenced by several factors including the type of PCA and the type of gas sensors. This is supported by available data [21] which indicated that the shortening of the settling time required by sensors to achieve a steady state can be achieved by means of a fast classification algorithm. Nonetheless, the performance of PCA can also be affected by the original or source of the odour. For example, while ANN was highly sensitive to rotten beef with fresh fish, KNN had the uppermost sensitivity and reasonable specificity to rotten fish with fresh beef. This suggests the need for integration of an array of gas sensors with a wide scope of selectivity coupled with appropriate pattern classification algorithm. Nonetheless, the use of great numbers of sensors could affect the e-nose portability and onsite application. Alternatively, the development of a variety of e-noses meant for localized use for particular meat and fish products could address this limitation. According to other researchers [7], odour classification relies on the constructed database that characterizes the different odour footprints. As such the design and development of e-nose system can vary depending on the differences in odour foot prints. This suggests the difficulty that could be faced in designing and developing a gas sensing system that can universally be used due to the complexity of meat volatile compounds.

In the other experimental trial [11], a sensor system was applied into a Raspberry Pi supplied with three MOS gas sensors and one color sensor as the freshness level identifier tools of meat. Pattern recognition power-driven by an artificial neural network (ANN) was utilized to identify meat's freshness. Three levels of freshness were tested (fresh meat, semi altered and altered meat). The voltage value of the gas sensor in clean air was employed as a reference of the created e-nose system [11]. During measurement, the voltage values of three gas sensors form a pattern that represents the state of a fresh meat. The voltage values of gas sensor when compared with that of clean air did not show significant difference. They attributed this to the condition of fresh meat that does not give out a vicious smell. Further testing with semi altered meat sample (i.e. meat with unpleasant odor, but with less concentrated aroma) indicated an increase in the voltage values on the three sensors as compared with the results of fresh meat sample.

The results generally demonstrated responses of the three sensors to the aroma produced by meat during its decay process. Nonetheless, half rotten meat was at times identified as rotten meat which was attributed to their tiny dissimilar patterns. The identification error was linked with unequal environmental condition in which the meats undergo dissimilar decomposition. The other identified challenge concerned the measuring of freshness level in ambient air, in which case the air condition will affect the measurement. They concluded that the system had 100% degree of success in identifying fresh meat and non-fresh meat (i.e. half- rotten and rotten meat). Nonetheless, the results implies the accuracy of the sensors can well be realized when the spoilage stages differs greatly.

In the other research [17] the use of e-nose in assessing the freshness of shrimp (*Penaeus vanmamei*) stored at 5°C was studied. E-nose was used alongside sensory evaluation and TVBN. The output voltage of 6 gas sensors were evaluated using PCA and the three principal components of PCA achieved accounted for 86.97% of total variation, and they were applied to develop a model to estimate the shrimp freshness with Fisher Liner Discriminant. The discriminant rates were 98.3% for 120 modeling sample data, and 91.7% for 36 testing sample data. It was concluded that the model could be definitely used to evaluate the freshness of shrimp with better accuracy. Other researchers [19] on the other hand examined quality variation in fresh chicken meat (based on volatile fatty acids - VFA) during storage using the MOS sensor system and assessed against the results of traditional chemical measurements. The variations of VFA in chicken meat (stored at +4°C) during the aging process determined by traditional chemical analysis method showed that both meat samples kept fresh for the first 4 days and only after this time the spoilage of thigh meat was noticed i.e. VFA began to increase. Minced chicken breast meat (that is less fatty) started to spoil after 5 aging days and it was totally spoiled one day later than the thigh meat. The initial pH values were 6.02 and 6.21 for chicken breast and chicken thigh, respectively, which fall within the limits of 5.6 and 6.2 indicating product freshness. Though the pH of chicken meat increased with time and is considered as one of the important parameters for evaluation of freshness, results did not give any clear and consistent information about spoilage progression. The pH did not show any significant correlation with the signals of sensors. They attributed this inconsistence in pH meat freshness evaluation to its variation dependence on many factors. On the other hand, the relations between the responses of CH, NH_3, and O_3 e-nose sensors and VFA concentration indicated that the best results were obtained using CH sensor. The highest correlation was recorded between CH sensor output signals in the fresh chicken meat samples gauged by e-nose and VFA concentration values measured using a traditional chemical method (R^2 = 0.89). Similarly assessment of the freshness of chilled yellow chicken meat using both traditional methods namely sensory evaluation, adenosine triphosphate (ATP) and inosine monophosphate (IMP) contents and an e-nose was made [12]. On the basis of the results it was concluded that traditional methods and e-nose technology are appropriate for evaluating freshness and e-nose is suggested to evaluate freshness of chicken meat due to superior speed, simplicity, and accuracy. Evaluation of the response of MOS sensors to specific chicken odour [19] in which one of the test samples was the meat of yellow chicken that was fed by maize, the results revealed that a specific breeding method affects taste, colour and odour of such type of chicken meat. This suggests that in the case of a wide variability of localized bred based foods, functionality of e-noses could be affected (that is, could be place bound, confined or localized) due to the effects of traits on scent signature. In another study [14] researchers made an electronic device integrated with biosensors that can detect food spoilage. They used sensors that can measure different parameters of food like pH, moisture and ethanol level. The device consisted of a microcontroller Arduino Uno, Bluetooth module, electrical and bio sensor like pH sensor, moisture sensor and gas sensor. They examined freshness of a variety of foods based on the depicted trend of the studied parameters with passage of time which indicated good to use [14].

Previous researchers [18] investigated changes in volatile compounds and the effects of different temperatures on the development of volatile compounds during storage of capelin by gas sensor measurements, sensory evaluation, and Total volatile bases (TVB) analysis. The e-nose consisted of an array of eight electrochemical gas sensors and a temperature sensor. Capelin samples were stored at 5 and 0°C for 8 days, and the effect of 0.2% added acetic acid was assessed at 5°C. The results showed that CO and SO_2 sensors from Dräger and the NH_3 sensor from City Technology were most sensitive toward the standard compounds tested and also showed the most characteristic responses to the capelin headspace. The highest intensity of signals, with early detection of spoilage was indicated by NH_3 sensor among the three sensors (CO, NH_3 and SO).

The correlation analysis of results between TVB measurements of capelin and the response of the NH_3 and CO sensor to capelin headspace in the 0°C samples was greater for the NH_3 sensor (r0°C = 0.98), than for the CO sensor (r0°C = 0.92). The differences in sensitivity were attributed to dissimilar sensitivity to different compounds e.g. CO sensor is insensitive toward amine. During the final few days of storage, the responses of the sensors increased more than the TVB values. The observation was associated with poor sensor selectivity and ability to detect a wide range of several very volatile degradation compounds which get formed at advanced phases of spoilage. This further suggests the need of integrating several sensors.

The enhanced response of the sensors in advanced spoilage lowers the correlation between sensors and TVB values in the 5°C series (r5°C = 0.89 for the NH_3 sensor and r5°C = 0.90 for the CO sensor). The descriptive sensory evaluation of the odor of capelin indicated the coincidence of the first spoilage and stale odors with TVB values of around 40-50 mg of N/100 g and when the odor of the capelin was putrid and the TVB values had increased to about 80 mg of N/100 g. The results of the gas sensor measurements demonstrated good reproducibility, and their responses correlated well with classical TVB measurements. The calibration of sensors in the study [18] was done using different standards for each sensor; ethanol represented alcohols used to calibrate the CO sensor, dimethyl disulfide for sulfur compounds to calibrate the SO_2 sensor, and TMA for amines to calibrate the NH_3 sensor. This implies lack of a standardized calibration procedure.

Other researchers [13] monitored the pork meat freshness at four distinct grades (High, Medium, Low, and Spoilage) which were established using the sensor value and model equation. A single gas sensor supported with temperature sensor and humidity sensor as auxiliary sensors and

RFID (radio frequency identification) tag were used to establish the food poisoning index. Temperature, humidity, and gas concentration of the meat stored in environmental conditions, were compared to establish the relationship between meat freshness and the sensor signal. The reliability of the system was confirmed by performing experiments on pork and comparing to the experimental results of an e-nose (NH_3 sensor output) and Total Volatile Basic Nitrogen (TVBN) measurements (Table 1). The researchers' [13] confirmation of the output voltage of the sensor for each freshness grade by experimentation is described in Table 1 from the experimental data.

The spoilage detection by e-nose against TVBN measurements are reflected in Table 1. The spoilage detection by NH_3 sensor output – mV coincided with the spoilage established by the TVBN value of >25 mg/100 g.

Table 1:

Description of meat freshness and comparison of the experimental gas sensor results with the existing method

Freshness Status	NH_3 sensor output - mV	Content	TVBN (mg/100g)
High	< 630	Very fresh	10.95
Medium	630-730	Can be eaten	10.95 – 16.94
Low	730-100	Food Poisoning may occur	16.94 - 25
Spoilage	>1000	Spoilage	>25

Source: Eom et al. (2014)

In the Table 2 it is indicate a comparison of the RFID technology experimental results with other method (E-nose and TVBN). The experiment confirmed similar experimental results (Table 2) as for the existing methods.

Table 2

Comparison of the experimental results with the existing methods (in days)

Status	Proposed system (Day)	Electronic Nose (Day)	TVBN (Day)
High	< 1.25	< 1	< 0.9
Medium	1.25- 3.12	1 – 3.3	0.9 – 3
Low	3.12-6.96	3.3 - 7	3-7
Spoilage	>6.96	> 7	> 7

Source: Eom et al. (2014)

By combining the RFID technology in their trial with a gas sensor, temperature sensor, and humidity sensor, they established the relationship between meat freshness and gases released.

These results [13] suggest that the accuracy and reliability of the sensor in freshness quality prediction can be further improved if complemented with temperature and humidity sensors since the temperature and humidity of the storage environment has a direct relationship with the freshness of the sample under consideration. According to documented data [22] RFID systems are favoured over other identification and inventory techniques mostly due to their non-line-of-sight operation and capability to function in adverse environments. This is attributed to the RFID sensors combination with several measured parameters from the resonant sensor antenna with multivariate data analysis and deliver a unique ability of sensing with rejection of environmental interferences with a single sensor.

More or less similar advancements in e-nose technology have been demonstrated in some trials by other researchers [7]. They detected spoiled meat and its degradation level using an e-nose equipped with metal oxide-based gas sensors supported by humidity and temperature sensors. Classification by PCA method indicated well separation into three distinct groups namely chicken free, chicken to become rotten and rotten chicken. Also in another study [1] tilapia fish spoilage was monitored based on the application of a single gas sensitive gel material coupled to an optical e-nose. The changes in the optical signal produced by the gas sensor, once exposed to the headspace of fish samples stored at ambient situation, were correlated with the mesophilic bacteria counts during storage time. The results of the microbial examination were consistent with the results achieved by the optical gas sensor. The amplified relative response of the sensor matched the increase in bacterial counts in fish, implying that the sensor was detecting specifically the volatile compounds produced by the microorganisms that caused the fish to deteriorate. The results demonstrated that a single optical sensor was efficient in monitoring the quality of fish. The largest change in the optical signal happened exactly while the biggest increase in bacterial counts was examined and reached the limit to declare the fish's unsuitability for human consumption (above 6 - 7 log CFU/g). However, the decline in the baseline of the optical signal showed structural alteration in the sensing material, which may imply the need to apply it as a non-reusable component of the sensing device. They considered the observation as a weakness attenuated by the low cost of the sensing film. Overall they conclude that the good correlation between changes in optical sensor signals and the extent of mesophilic bacterial growth evidences its potential application for tilapia fish freshness monitoring.

These results [13] suggest that the accuracy and reliability of the sensor in freshness quality prediction can be further improved if complemented with temperature and humidity sensors since the temperature and humidity of the storage environment has a direct relationship with the freshness of the sample under consideration. In view of the available data [22] RFID systems are favoured over other identification and inventory techniques mostly due to their non-line-of-sight operation and capability to function in adverse environments. This is attributed to the RFID sensors combination with several measured parameters from the resonant sensor antenna with multivariate data analysis and deliver a unique ability of sensing with rejection of environmental interferences with a single sensor.

Though the results from the experimental trials indicate the high potential of e-noses in freshness quality evaluation, however, the method can only be effectively used when benchmarked against other methods which could act as reference points for quality assessment. Nevertheless, the sensor output (mV) levels established by other researchers *[13]* to define the degree of freshness (high, medium, low and spoilage) can however enable the usage of e-noses independent of the reference method. This enhancement of e-noses with auxiliary sensors and RFID (radio frequency identification) tag could possibly explain these advancements.

The existing data indicate that sensors have dissimilar reactions to different gases/ volatile compounds to be detected which can also be influenced by other external factors such as breeding [19]. The efficiency of the gas sensors could thus depend on the uniqueness of each system to particular odour foot prints. It can thus be deduced that the data on aroma composition which are reflective of the properties of meat products are the most desirable information for an efficient design and development of effective gas sensing systems.

The available literature [9] shows that some sensors such as quartz-resonator sensors and oxide semiconductor sensors

are operated in the high-temperature range of 300°C to 400°C and their responses are simply affected by humidity. It is also documented [22] that MOS sensors operate at temperatures between 200°C and 650°C as the organic volatiles transmitted to the sensing surface need to be oxidized which results in the alterations of electrical resistance. On the other side it is reported [9] that a potentiometric gas electrode is operated at room temperature and it is not affected by humidity.
The variations in responses of gas sensors due to the influence of humidity and temperature could further imply localization of the application of gas sensors in quality estimation unless if equipped with self-calibration and self-correction for variable ambient conditions. Moreover, the recognition by e-nose depends on the pattern-recognizer comparison between the pattern of measurements and the stored patterns of known materials.
Unlike gas sensors which use specific sensors to measure particular single attributes and quality and safety in the food and beverage industry, information can also be obtained from arrays of non-specific sensors with partially overlapping selectivity and treating the data obtained with pattern recognition software [15].
A recent study [11] that identified three levels of freshness (fresh meat, half-rotten meat, and rotten meat) using an e-nose, employed the voltage value of the gas sensor in clean air as a reference / for calibration of the created e-nose system [11]. Other researchers [18] on the other hand in their measurements by means of standard compounds demonstrated that the sensitivities of identical sensors are dissimilar thus new gas sensors have to be calibrated. Nonetheless, specific validation procedures for different sensors for specific usage have been lacking. Furthermore, [18] they demonstrated the use of different standards for each sensor, where ethanol was chosen to represent alcohols to calibrate the CO sensor, dimethyl disulfide for sulfur compounds to calibrate the SO_2 sensor, and TMA for amines to calibrate the NH_3 sensor. However, little has been documented in subsequent trial studies on calibration procedures, implying the need for development of standardized calibration procedures.

4. Conclusions

The available literature data on e-nose experimental trials indicate the high potential of e-noses in freshness quality evaluation; however, the method can effectively be used when benchmarked against other methods which act as reference points for quality assessment. The use of the e-nose without relying on reference methods requires the establishment of threshold levels of volatile compound detection which can define the level of freshness or spoilage or else be used alongside other conventional methods. Recent development however suggests the sensor output (mV) levels can define the degree of freshness of meat items depending on design modifications. Although, the efficiency and effectiveness of e-noses depend on the type, selectivity and sensitivity of an array of gas sensors, however they can further be enhanced if coupled with appropriate pattern classification algorithms. Nonetheless, the use of great numbers of sensors could affect the e-nose portability and onsite application. Alternatively, the development of a variety of e-noses meant for localized use for particular meat products could address this limitation**.** This is due to the fact that odour classification relies on the constructed database that characterizes different odor footprints. As such the design and development of an e-nose system can vary depending on the differences in odour foot prints. This suggests the difficulty that could be faced in designing and developing a gas sensing system that can be universally used due to the complexity of meat volatile compounds. This may further be explained by the sensors' dissimilar reactions to different gases/ volatile compounds to be detected which can also be influenced by other external factors such as breeding method which affects taste, colour and odour of meat items which reflects the effect of traits on scent signature. In addition, though the concentration threshold is an important element in the detection and sensitivity of e-noses to volatile compounds, but also the temperature at which volatilization occurs, that is, the lower the boiling point the higher the sensitivity and vice versa. It can thus be deduced that data on aroma composition which are reflective of the properties of meat products are the most desirable information on an efficient design and development of effective gas sensing systems. Furthermore, the functionality of e-noses can be further improved if equipped with self-calibration and self-correction for variable ambient conditions.

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5. Competing interest

The author declares that has no competing interests.

6. References

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