Journal of Animal Research: v.12 n.05, p. 601-611. October 2022

DOI: 10.30954/2277-940X.05.2022.1

Novel Interventions in Monitoring of Meat Quality and Spoilage: A Review

Upender[1*], Sudesh Kumar[2], Suvidhi[3], Krishna N. Bansal[4] and Ajay Kumar[5]

[1]Division of Veterinary Public Health & Epidemiology, ICAR-Indian Veterinary Research Institute, Izatnagar, U.P., INDIA
[2]Bacteriology Lab, National Centre for Veterinary Type Cultures, ICAR-NRCE, Hisar, Haryana, INDIA
[3]Virology Lab, ICAR-National Research Centre on Equines, Hisar, Haryana, INDIA
[4]Department of Veterinary Gynaecology and Obstetrics, CVAS, RAJUVAS, Navania, Rajasthan, INDIA
[5]Department of Animal Genetics and Breeding, CVAS, RAJUVAS, Bikaner, Rajasthan, INDIA

**Corresponding author: Upender; E-mail: yadavupender10@gmail.com*

Received: 13 July, 2022 **Revised:** 28 Aug., 2022 **Accepted:** 04 Sept., 2022

ABSTRACT

Over the last two decades, the technological advancements in terms of monitoring the meat quality at various steps of the food chain have been seen, *i.e.,* at the slaughter house, processing step, packaging step, transport, storage step, etc. which have been employed for the benefit of consumer health all over the world. The most efficient and rapid technologies that are a tool in measuring the meat quality are spectroscopy, LAMP, e-nose, PCR, etc. which are quite sensitive, specific, and less manpower consuming, thus, gaining more popularity and success. The spectroscopy techniques make use of electromagnetic radiations and their interaction with the atoms of the meat samples leading to the absorption or emission of the light and consequently its spectral images and electric signals. The LAMP is an advanced version of the conventional Polymerase Chain Reaction (PCR_ providing a rapid, sensitive, specific, and time-saving method of the meat quality assessment. The electronic nose (e-nose) technology is a versatile technique based on chemo-sensors and computation methods. It usually makes use of chemo-sensors such as metal oxide semiconductors, metal oxide semiconductor field-effect, conducting polymers, etc. Although, many technological advancements have been made still PCR is one of the easy-to-use techniques among researchers. The HPLC technique is a rapid and sensitive technique that when coupled with the detectors helps in the detection of the target analyte in the meat sample. In this chapter, we discuss the above technologies in detail with their application in the meat quality and spoilage assessment.

HIGHLIGHTS

- LAMP is a rapid and sensitive technique for monitoring of the meat quality.
- HPLC is the best tool for the quantitative evaluation of meat quality.

Keywords: Meat quality, Meat spoilage, LAMP, HPLC

The term meat quality refers to the sum of all the properties in terms of physical, chemical, technological, bacteriological and aesthetic characteristics of the meat that contributes to the acceptability of the meat (Taheri-Garavand *et al.,* 2019) whereas the term meat spoilage refers to the alteration in the sensory attributes of the meat consequently making it unfit for human consumption. The meat spoilage can take place due to various factors such as fluctuation in the relative humidity, pH, temperature, micro-organisms, water activity etc. which ultimately deteriorate the meat quality (Pothakos *et al.,* 2015).

As the world population is exploding, it also causes an enormous increase in the burden over the food sector to meet the food requirements of the human population with the safe and sound food. The meat is considered as a highly nutritious and perishable food item which is

How to cite this article: Upender, Kumar, S., Suvidhi, Bansal, K.N. and Kumar, A. (2022). Novel Interventions in Monitoring of Meat Quality and Spoilage: A Review. *J. Anim. Res.,* **12**(05): 601-611.

Source of Support: None; **Conflict of Interest:** None

rich in highly digestible animal proteins, minerals and vitamins with the limited shelf life (Baltic *et al.,* 2015). The nutrient enrichment characteristic of meat makes it necessary to perform regular quality checks from point of public health. The traditional methods of assessing the meat quality like extract release volume, total viable count, pH measurement, standard plate count via culture etc. are not able to meet the pace of the enormous increase in the meat production at large scale and are very time consuming, requires skillful persons and inefficient (Vasconcelos *et al*., 2014). So, to meet the increased pace, there was much urgent need to develop or evolve the novel technologies that will be time-saving and efficient with high sensitivity and specificity. It leads to emerging of the spectroscopy technique, LAMP, e-nose, PCR, etc. The spectroscopic method presents a highly efficient, labour-saving, less time-consuming, sensitive and specific method for meat quality assessment (Hassoun *et al.,* 2020). Other techniques such as LAMP, an upgraded version of conventional PCR in terms of less time consumption, less complexity, sensitivity and specificity. It makes use of 4-6 primers at once targeting 6-8 genome sites of the microbial DNA yielding 50-fold more amplicons as compared to conventional PCR making it a better option in meat quality assessment (Kumar *et al.*, 2017). The electronic nose commonly abbreviated as e-nose technology is a versatile technique that helps to make a quick quality check for meat quality assessment. This e-nose makes use of the principle of simulating the human nose in cognitive recognition using the chemo-sensors and multivariate data analytical methods like PCA, MLR, LDA, etc. The most common chemo-sensors used in electronic noses are the metal oxide semiconductors (MOS), metal oxide semiconductor field-effect transistor (MOSFET), conducting polymers (CP) etc. The PCR, although considered to be a conventional technique, still it is most commonly used technique by researchers (Fletcher *et al*., 2018). The major advantage of these novel interventions is that they can be applied inline, online, or at the end of the processing thus helpful in providing the real time picture of the meat quality and meat spoilage simultaneously along with preventing the huge economic losses to the industrial processors. Among all the above interventions, the most commonly used intervention is the HSI, *i.e.,* hyper-spectral imaging technique which provides the pin point location of the defect in terms of meat quality (Xiong *et al*., 2015). The LAMP technique helps in the detection of the microbial, fungal and parasitic contamination of the meat by targeting the genes of the microbes which are responsible for production of the toxins such as *E. coli*, *Salmonella* spp. etc. in raw read meat, cooked meat, vacuum packaged meat etc. (Kumar *et al*., 2017). The HPLC coupled with detectors works on the principle of the separation of the analyte from the solution phase and detecting it using UV-absorption based detectors. It is rapid as compared to the conventional method of the identification of the analyte. Here, we discuss all the above interventions in detail and their applications in assessment of the meat quality.

Spectroscopy Techniques

This method of assessing the meat quality and meat spoilage is based on some concepts of physic-chemistry like electromagnetic radiations, atoms, emission, absorption, excitation of atoms, atom nuclei etc. The principle on which the spectroscopic techniques operates is that the interaction of the electro-magnetic radiations/ waves with the molecules/atoms of the food sample leads to either emission or absorption or transmittance or scattering of new light/waves/radiations which then ultimately captured by spectroscope in a unique pattern, *i.e.,* spectral image which then get analyzed by various algorithmic operations using computer yielding the output regarding the various extrinsic or intrinsic meat quality parameter (Hassoun *et al*., 2020). Since there are a lot of variations in the electromagnetic spectrum, so, there are various types of spectroscopy methods like NIR (Near Infrared), VIR (Visual infrared), MIR (Mid-infrared), NMR (Nuclear magnetic resonance), HIS (Hyper-spectral imaging), Molecular fluorescence spectroscopy, etc. Mainly, the spectroscopic methods are divided into two categories based on two mechanisms, *i.e.,* absorption-emission spectroscopy methods and vibrational spectroscopy methods. The previous category counts for absorption spectroscopy in UV & visible range, molecular fluorescence spectroscopy methods while the latter category counts on MIR, NIR, Raman scattering, HSI, and NMR spectroscopic techniques.

The absorption spectroscopy in the UV-visible range technique deals with the radiations in the range of 190-800 nm (Noorjahan *et al.,* 2019). In this technique, the incident electromagnetic radiations interact with the food sample molecules and in turn, the food molecules absorb the

radiations, the radiations absorbed by food molecules then are detected by absorption spectroscopy and get converted into the electronic signal which gets analyzed by various multivariate analytical tools with the help of computerized technology.

The other spectroscopic method is the molecular fluorescence spectroscopy method. In this method, the incident electromagnetic radiations get emitted instead of being absorbed. Here, the molecules return to their original shell or orbit while in a relaxing transition. This process leads to emission of the light but sometimes the molecules may get excited also after absorbing the photon from incident radiations. Here, we need chromophores, and we know that all chromophores are not fluorescent; hence it leads to higher sensitivity as compared to other methods of spectroscopy. But the limitation of this method is that not all meat samples contain fluorescent tags/labels, so, there is a need of the addition of fluorescent labels to the sample before carrying out the examination. The other lacuna of this method is that the detection of the fluorescence signal is carried out only in one direction which is not the same as that of the incident light that is why it yields a higher signal-to-noise ratio which ultimately limits the detection range of this technique (He *et al.,* 2015).

The MIR (Mid-infrared) spectroscopy method is a type of vibrational spectroscopy method which works in the narrow range of the electromagnetic spectrum, *i.e.,* 400-4000 cm^{-1} and consequently produces the outputs also within narrow bands. This technology is mainly associated with the detection of the specific functional groups or due to the movement of the whole molecule backbone (Zhao *et al.,* 2014). The other variant of vibrational spectroscopy involves the NIR spectroscopy which stands for narrow infrared spectroscopy. It is a novel, non-thermal and nondestructive technology getting very popular and has wide applications in the analyses of the meat and food sector. It deals within the range of 800-2500 nm of the electromagnetic spectrum. It works on the principle of exploiting the transitions corresponding to the overtons and combinations of the fundamental vibrations. Since these transition frequencies are very less, that is why NIR spectroscopy operates at a very wide band. The NIR spectroscopy have the capability of simultaneously measuring a lot of quality attributes such as tenderness, cooking loss and sensory characteristics, water holding capacity, pH and drip loss. The other advantage of the NIR spectroscopy is that the NIR rays have lower absorptivity which leads to higher penetrability and less scattering tendency. The NIR spectroscopy provides the compositional details of the meat sample very well but not the spatial details due to its limited spatial resolution (Dixit *et al.,* 2017).

The Raman scattering is a type of spectroscopy method which is very helpful in assessing the quality check of the meat items which are packaged and shipped. It is based on the principle that electromagnetic radiation induces a change in molecular polarizability so that asymmetrical and non-infrared active molecules also become active and produce a signal (Zhang, 2017). It usually supplements the MIR spectroscopy technique in the assessment of various parameters of the meat. The hyper-spectral imaging (HSI) is the latest intervention in spectroscopy methods for the assessment of meat quality. It is a spectroscopy technique with the features of both the spectral imaging as well as spatial information capture technique. The HSI can be defined as the capturing of all images for a pixel in a whole spectrum (Xiong *et al.,* 2015). It permits the spatial as well as spectral details collection of the meat sample. It is mainly used for heterogeneous meat samples and is not suitable for homogenous meat samples as in the homogenous meat samples; there is homogeneity in various spectral images which can't yield any fruitful outcome. HSI provides the spectral measurements of the entire surface area of the meat sample. It is highly beneficial in grading the meat by evaluating various extrinsic as well as intrinsic properties of the samples of the meat that has been analyzed (Fu *et al.,* 2019). The NMR (nuclear magnetic resonance) spectroscopy is based on all the perspectives of all the specific atomic nuclei. This technology deals with the qualitative, quantitative, and structural properties of the meat sample. Another variant of the NMR is H-NMR spectroscopy which is more specific and advanced and generally referred to as high resolution nuclear magnetic resonance spectroscopy technique. The H-NMR spectroscopy provides all the information regarding the meat sample, *i.e.,* chemical variability along with the molecular structure of the constituents of the meat sample that has been analyzed (Sogila *et al.,* 2019). One important point regarding all spectroscopic methods is that all these techniques generate a lot of the statistical data which requires the various multivariate analytical methods applied to analyze the findings regarding the meat sample

like the partial least square model (PLS), root mean square analytical model (RMS), random forest regression method (RFR), etc. Along with it, spectroscopic techniques require robust computing software and devices for algorithmic calculations.

Applications of various spectroscopic methods in meat quality and meat spoilage assessment

To estimate the content of protein, fat, and water

The most commonly used spectroscopic method for the above purpose is the NIR spectroscopy along with the MIR spectroscopy. It has been successfully applied for the estimation of the above contents with great accuracy. The above two technologies can be used along with the chemometers for the quantification of the protein, fat, and water (Kartakoullins *et al.,* 2019). They conducted the experiment on the salted meat ham meat samples at a temperature range of -14° to 25°C. The experiment was carried out at 740- 1070 nm and employed the partial least square (PLS) and random forest regression (RFR) model. Similarly, the chemical composition of the meat samples can also be determined with the help of NIR spectroscopy methods and the water content has been quantified with the help of hyper-spectral imaging (HSI). Another application of the NMR spectroscopy and H-NMR involves the estimation of the moisture content, free fatty acids composition, and water-soluble low molecular weight compounds at various stages of the processing chain such as raw red meat or hams (Tao *et al.,* 2018).

The applications of the NIR spectroscopy methods in the meat quality and meat assessment sector are as follows

Water content

The NIR spectroscopy is highly efficient in measuring the water content of the meat samples. The water content of the meat is positively associated with the spoilage of the meat, but less water content also imparts a negative appearance to the outer surface of the meat and meat products (Fig. 1). A study carried out by Zhang *et al.,* 2012 on the fresh loins (pork) for detecting the water content by application of the NIR had been successful within the range of 200-1750 nm using the partial least square (PLS) and multivariate linear regression (MLR) models. The models had been evaluated with the help of correlation coefficient (R) and root mean square error (RMSE). The PLS model gave better results with an optimum principal component of 15, the average water activity of 0.73 with R_C of 0.90, and RMSEC of 0.50.

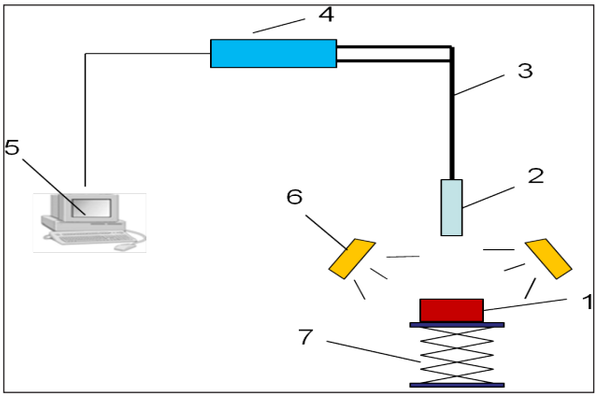

Fig. 1: The above flowchart shows VIS/NIR spectral system (Peng Y. *et al*., 2015), where, 1. Sample 2. Optical probe 3. Fiber 4. Spectrometer 5. PC 6. Light source 7. Platform

pH value

NIR spectroscopy method had also been successfully applied in detecting the pH value of the meat samples The pH value should be in a range for the growth of a particular microbe in the meat.

Tenderness

The VIS/NIR spectroscopy technique is successful in estimating the value of WBSF value which is the indicator of the tenderness. The study was carried out on the longissimus dorsii muscle sample of the beef. The HSI captured both spectral as well as spatial data of the meat sample and this data had been processed immediately in the VIS/NIR spectroscopy method (Wu *et al.,* 2012). The results obtained were the value of WBSF value of 50.41 with standard deviation of 18.79 and coefficient of variation value of 0.37.

Safety attributes

It involves the compounds which are formed in the meat

samples itself after the slaughtering either during improper preservation methods or improper additive and lead to the spoilage of the meat samples making it unfit for the human consumption.

TVB-N

It stands for total volatile basic- nitrogen. It is considered as an important chemical factor as the quality check for the meat spoilage or meat freshness (Leng *et al.,* 2021). The VIS/NIR spectroscopy method had been used for assessing the TVB-N in pork meat samples. The main point is that, for the estimation of TVB-N, we need large number of meat samples. The NIR spectroscopy showed better results with PLS regression model with the coefficient of TVB-N to be 0.9 with 92% accuracy.

Water activity measurement

The NIR and MIR spectroscopy technique plays an important role in the estimation of water activity. An experiment carried out by Collell *et al.* 2012, a_w have been estimated in fermented sausages during the drying stage. The best results are obtained with PLS with R^2 of 0.84 and RMSEF value of 0.007% at a range of 830-2500nm.

Oxidative changes in the meat fats

Usually, the fat is highly prone to oxidative changes and thus undergoes the hydrolytic changes which lead to off-smell in the meat products. In this context, HSI is the best spectroscopic technique that has been used. According to a study carried out by Aheto *et al*., 2020, for the purpose of quantification of the oxidation degree of fat in pork belly, he estimated the TBARS (thiobarbituric acid reactive substances) by means of HSI and PLS model with R^2_p value of 0.77. The actual oxidation of the fat lipids can also be estimated by spectroscopic methods like H-NMR (High resolution NMR).

Sodium salt monitoring

In today's modern world, the sodium salt in the diet has been restricted to a large extent as it is associated with negative effects on circulation. But sodium salt is necessary for inhibiting the growth of microbes in the meat products and thus enhancing the shelf life of the meat products (Hassoun *et al.,* 2020). Among various spectroscopy techniques, the best technique for this purpose is impedance spectroscopy which relies on the principle of the correlation between conductance and the concentration of ions in the sample.

LAMP (Loop-Mediated Isothermal Amplification)

The term stands for loop-mediated isothermal amplification. It is a novel, rapid, sensitive, and specific method for amplification of the targeted portion of the nucleic acid. The conventional techniques for the detection of the microbial spoilage of meat samples need the active cells to be present in the meat sample. They usually get failed in case of amplification of VBNC (Viable but non-culture-able cells), although the presence of VBNC cells indicates that meat already gets contaminated to a higher extent or spoiled already (Li *et al*., 2014). In such cases, LAMP plays an important role in the amplification of the VBNC targets. It is less time-consuming as compared to the conventional techniques and rapidly amplifies the target region of nucleic acid under isothermal conditions (65°C) in the reaction vessel (Wong *et al.,* 2018). It mainly requires 4-6 primers along with thermos-stable DNA

Table 1: Various experiments involving the application of the spectroscopic techniques in the meat processing and spoilage detection

Experiment objective	Spectroscopic technique	Chemo-metric method used	References
Quantification and spatial characterization of moisture and NaCl content of the Iberian dry-cured ham slices	HSI(900-1700 nm)	PLSR	Novell *et al.,* 2015
Monitoring composition and digestibility of ripened bresaola	H-NMR	ANOVA, LSD	Picone *et al.,* 2019
Determining water distribution within beef during dehydration	HIS(380-1700nm)	PLSR, MLR	Wu *et al.,* 2013
Impact of crystal size on salt (NaCl) uptake and water activity (a_w) of dry-cured pork	HSI(400-1000nm)	PLSR, CARS-PLSR	Aheto *et al.,* 2019

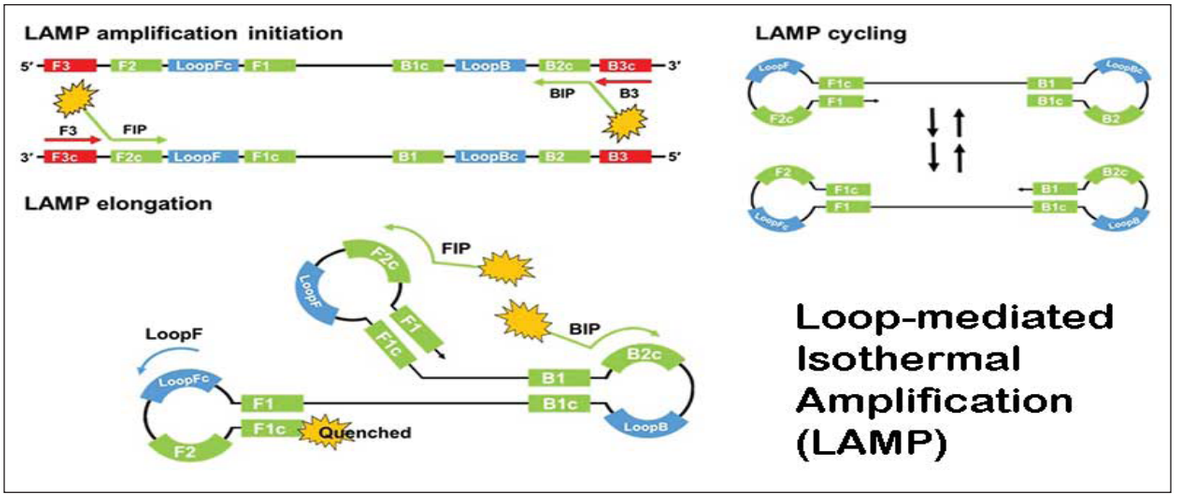

Fig. 2: LAMP process flow chart (Hardinge *et al*., 2019)

polymerase (*Bacillus stearothermophilus* polymerase) for the amplification of 6-8 target sites at one time resulting into the formation of 50 times more amplicons as compared to conventional PCR (Fig. 2). There are various methods for the detection of the end product of the LAMP.

Turbidity based methods: It helps in detecting the final product, *i.e.,* amplicons on the principle that magnesium (Mg^{2+}) added to the reaction mixture get combine with the pyrophosphate ions (by product of LAMP) and forms white gel like coagulum in proportion to the quantity or the extent of the target microbial species DNA or RNA in the analyzed meat sample (Chen *et al.,* 2018). The limitations of this method are that sometimes it also gives false positive because it also detects certain other compounds after reaction of magnesium ions with them and form gel like coagulum and sometimes it fails to detect the amplicons when they are present at low concentration.

Nucleic acid targeted dye-based methods: There are certain fluorescent dyes which are having a special affinity for the nucleic acids, and they get intercalate with the DNA and produces the fluorescence in presence of LAMP amplicon (Lucchi *et al.,* 2016). The limitation of this method is that it is non-specific as it also gets intercalates with certain other elements of the matrix and shows fluorescence. An example of NA-based fluorescent dyes includes SYBR Green 1 dye which helps in the detection of the EHEC O157:H7 and emits green color as positive while negative is shown as orange color. Another example involves Ethidium monoazide (EMA) which exclusively detects viable EHEC cells.

Divalent cation-based dyes: These dyes needed to be added in pre- processing step with an objective of avoiding the contamination of the final product at last step. The magnesium ions in the reaction mixture/vessel continue to decrease as LAMP reaction progress and when a divalent chelating dye is added, it starts changing the color which is visible even with naked eyes or some other techniques (Gopinath *et al*., 2014). The examples involve HNB (hydroxy- napthol blue) which changes its color from violet to sky blue at the end of LAMP process. Another dye is Eriochrome black T (EBT) which shows its color change from initial purple to last sky blue (Nguyen *et al*., 2019).

Other methods: The other methods for the detection of the end result of the LAMP reaction involves lateral flow dipstick (LFD) method, Bioluminescent LAMP technique etc. The later method involves the conversion of inorganic pyrophosphate to the ATPs which gets utilized by firefly luciferase to emit light (Yang *et al.,* 2016). The LFD method involves the immobilization of the amplicons over a surface and addition of complementary labelled probes for hybridization of the amplicons and thus detection of the targeted nucleic acid has been carried out (Kumar *et al*., 2017).

Applications of LAMP in the assessment of meat quality and meat spoilage:

Species identification: The LAMP technique plays an important role in the species identification of the given meat sample. It involves the application of the primers targeting the mitochondrial DNA of various livestock species. The mitochondrial DNA is more sensitive, more specific and more stable to heat, cold and salt processing as compared to nuclear DNA. That is why; the mitochondrial DNA is more suitable for PCR as well as LAMP (Cho *et al.,* 2014).

Microbiological assessment of meat: The LAMP method is a rapid and facilitating method to detect the target DNA of the fungal, parasitic or bacterial species that pose a great health hazard for public health in context of the meat consumption. For, the identification of the microbial spoilage or contamination, the meat sample along with 4-6 primers targeting the toxin producing gene are incubated in a reaction vessel at a suitable temperature for a pre-determined time leading to the generation of the amplicons. The temperature usually kept at 65ºC for 60-65 minutes. For example, the LAMP study on *Salmonella* spp. for *inv*A gene had been carried out by Yang *et al.,* 2016 on ground beef and turkey meat at 60ºC for 75 minutes and the product (amplicons) had been detected with the help of bioluminescent technique which had detected up to 36 cells/reaction(sensitivity)(pure culture). In the same manner as for bacteria, the LAMP can be used very well for fungal and parasitic agent detection in the meat samples. The fungi produce several toxins out of which some are nephrotoxic, hepatotoxic etc. and are lethal to the public health. One such example is ochratoxin A which is produced by *Penicillium nordicum*. The LAMP method targeting the otapksPN gene (encodes for OTA through polyketide synthase) was carried out by Ferrara *et al.,* 2015 using the visual HNB dye method for detection of end product. The sensitivity in that process recorded was 100fg of purified genomic DNA and 100 conidia/reaction. The meat borne parasites also pose a public health hazard such as *Trichinella spiralis, Eimeria tenella* etc. The LAMP process is an improved tool in the detection of the meat origin parasites thus safeguarding the public health (Deng *et al.,* 2019).

HPLC

The term HPLC stands for High-Performance Liquid Chromatography. It is one of the highly efficient chromatographic techniques which work on the principle of the distribution of the analyte (from the sample loaded) between a mobile phase (eluent) and a stationary phase (column). The column plays the role of the heart in the HPLC method. The analyte is present in the mobile phase and is passed over the column via pressure equipment or system. Based on the chemical nature of the analyte (polar or non-polar) and of the stationary phase/column material (polar or non-polar), the compounds get separated or eluted out (Fig. 3). The eluted compounds are then detected with the help of ultraviolet radiation absorption protocol. The ultraviolet absorption depends upon the concentration of the analyte or the active principle or the target component which we are going to detect, and it leads to creation of the peaks on the chromatogram which then are coupled with the statistical analysis tools such as PLS-R (Partial least square regression) or PCA (Principal component analysis) to generate the meaningful interpretations (Choudhary *et al.,* 2015). HPLC has a variety of applications ranging from pharmaceuticals to the meat sector. In our context, the HPLC proves to be a rapid method of the identification of the various spoilage biochemical indicators such as formic acid, lactic acid, etc. (Sirocchi *et al.,* 2014; Pereira Da Costa *et al.,* 2015). It also helps in the estimation of the Total Viable Count which indicates the deterioration or the spoilage of the meat.

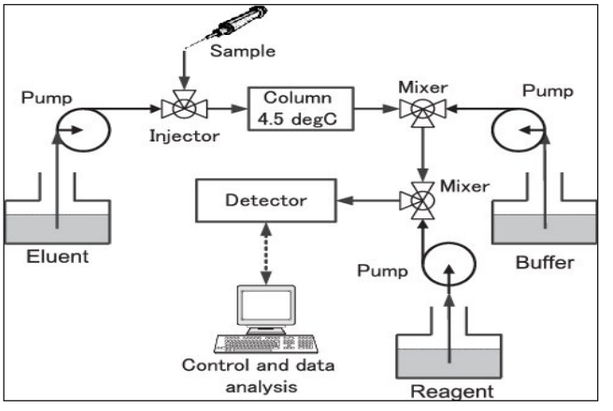

Fig. 3: Schematic layout of a HPLC system (Hatakeyama S. *et al*., 2014)

Polymerase Chain Reaction (PCR)

The PCR deals with the amplification of the target DNA strand following denaturation of the dsDNA and annealing

of the primer. It needs thermophilic DNA polymerase for the extension of the primers as the temperature range is very high. The PCR reaction is allowed to use for the objective of species identification as well as the replication of the nucleic acids which had contaminated the DNA (White *et al.,* 2013). Some pathogens are so highly infectious that their absence in the food sample is a must but during the conventional plating and microscopic examination, they might skip the process or sometimes require a very long time to grow like *Mycobacterium bovis* spp. So, in such cases, the PCR stands to be a better alternate for rapid detection (within 20-24 hrs) of the microbial agents in the food sample (Rodriguez-Lazaro *et al.,* 2014).

Electronic nose (E-nose)

The electronic nose is the machine operated olfaction technology which is used to simulate the cognitive function of human nose up to maximum extent (Wojnowski *et al*., 2017). As we know, the olfaction is a neural phenomenon in humans in humans and have unlimited variability and accuracy thus helps in providing an accurate information about the sensory attributes of the sample or the environment. In meat industry, the olfaction concept mainly applies to the mal odors formed over the head space of the spoiled meat that indicates its deterioration. The mal-odor is mainly due to production of biogenic amines or due to VOCs (Volatile Organic Compounds) which are gaseous in nature and get perceived by e-nose. "Odorants" term is applicable to those molecules that are light (molecular weight up to 300 Da), small, polar and often hydrophobic, such one example is alcohol. The term "complex odorants" refers to the mixture of combination of more than one chemical, *i.e.,* headspace of the coffee.

Basic concept of E-nose

The term E-nose basically refers to the chemical gas sensors equipped along with the computerized statistical processing technology with a broad sensitivity and selectivity for measurement of volatile organic compounds within the headspace over a sample (Górska-Horczyczak *et al.,* 2016). These chemical sensors correspond to the primary neurons as in human nose and the electrical signals generated by interaction of odor compounds with gas sensors corresponds to the secondary neurons of the human nose. In nutshell, the e-nose consists of an array of technology consisting of the "chemo-sensors" and computerized technology. A chemo-sensor is a device that is basically made up of metal oxide semiconductor (MOS), metal oxide semiconductor field-effect (MOSFET), conducting polymer (CP), etc. are capable of converting the gaseous chemical signals that are perceived onto their surface into electrical signals corresponding to the concentration of the atoms/molecules/ions present. These sensors usually consist of ceramic tube support with a platinum heater coil inside and semiconductors like SnO_2 coating on the outer aspect with any catalytic agent like platinum etc. The gaseous orders cause a change in the electrical resistance over the outer surface of the MOS chemo-sensor which creates an output electrical signal for analysis (Fletcher *et al.,* 2018). One can alter the performance of the chemo-sensor by deposition of thin (6-1000 nm) or thick film (10-300 micrometer) over metal oxide which can be achieved by physical or chemical or vapor deposition. The thin film provides faster response while thick films are less sensitive data producer. The manufacturing of thin film MOS is very difficult as compared to thick film MOS. The properties of an ideal chemo-sensor includes the low sensitivity towards humidity and temperature, medium selectivity, high sensitivity towards odors, chemicals and gaseous ions, high reproducibility, high stability, high reliability, short reaction time, short recovery time, better and easy to use calibration, simulate the cognitive function of human nose upto maximum extent, easily processible data output and small dimensions etc. The computing equipment make use of various statistical analytical tools such as MLR (Multiple linear regression), PLS (Partial least square), PCA (Principle component analysis), MLP (Multilayer perception) etc. A subunit called pattern recognition (PARC) is currently most common used tool for data analysis in e-nose. The data analysis can be done via three ways;

1. Graphical analysis using bar charts,
2. Multivariate analysis using PCA, LDA, MLR etc.
3. ANN (Artificial neural network).

The ANN stands for Artificial Neutral Network works on the principle of the cognitive process as human brain does. It consists of a set of interconnected processing algorithms operating in an arrangement of parallel. It consists of 03 layers- the first layer consists of gas sensor layer, the second layer consists of hidden layer and the last (3rd

layer) layer is called as output concentration layer (Jia *et al.,* 2018).

CONCLUSION

In spite of a lot of advantages associated with spectroscopic methods such as more sensitivity, more specificity, less time consumption, etc., there are certain limitations also associated with it. The major constraint associated with it is the production of enormous data which is too difficult to handle by ordinary analytical tools. It requires robust analytical tools which can handle such a volume of data. Adopting a combination of spectroscopy methods instead of a single method can yield better results. The LAMP technology is an easy, rapid, sensitive, and specific tool in today's meat sector. Nowadays, compact portable LAMP devices have been gaining popularity. The LAMP technology helps in the microbial spoilage detection as well as species identification of the meat. The conventional PCR technique is still the first choice among researchers. It is quite simple and easy to carry out, but it takes more time (21-24 hours). E-nose is a versatile technology that is having an array of applications like odor, a load of bacteria in raw meat, spoilage of vacuum packaged meat, and classification of meat samples up to 85% sensitivity. The limitations associated with the e-nose are that it is affected by the environmental humidity and temperature. The HPLC technique is a rapid technique and proves to be a potential way for the qualitative classification, and prediction of the microbial load of a meat sample irrespective of its storage conditions. But there are certain lacunae also, which involve the preparation of the sample by homogenization, use of high-quality columns, and application of the detectors along with the robust statistical analytical tools.

REFERENCES

Aheto, J.H., Huang, X., Xiaoyu, T., Bonah, E., Ren, Y., Alenyorege, E.A. and Chunxia, D. 2019. Investigation into crystal size effect on sodium chloride uptake and water activity of pork meat using hyperspectral imaging. *J. Food Process Preserv.*, **43**(11): e14197.

Baltic, M.Z. and Boskovic, M. 2015. When man met meat: meat in human nutrition from ancient times till today. *Procedia Food Sci.,* **5**: 6-9.

Chen, Z., Yang, T., Yang, H., Li, T., Nie, L., Mou, X., Deng, Y., He, N., Li, Z., Wang, L. and Li, S. 2018. A portable multi-channel turbidity system for rapid detection of pathogens by loop-mediated isothermal amplification. *J. Biomed. Nanotechnol.*, **14**(1): 198-205.

Cho, A.R., Dong, H.J. and Cho, S. 2014. Meat species identification using loop-mediated isothermal amplification assay targeting species-specific mitochondrial DNA. *Korean J. Food Sci. Anim. Resour.*, **34**(6): 799.

Choudhary, A., Radhika, M., Chatterjee, A., Banerjee, U.C. and Singh, I.P. 2015. Qualitative and quantitative analysis of Potentilla fulgens roots by NMR, matrix-assisted laser desorption/ionisation with time-of-flight MS, electrospray ionisation MS/MS and HPLC/UV. *Phytochem. Anal.*, **26**(2): 161-170.

Collell, C., Gou, P., Arnau, J., Munoz, I. and Comaposada, J. 2012. NIR technology for on-line determination of superficial aw and moisture content during the drying process of fermented sausages. *Food Chem. X*, **135**(3): 1750-1755.

Deng, M.H., Zhong, L.Y., Kamolnetr, O., Limpanont, Y. and Lv, Z.Y. 2019. Detection of helminths by loop-mediated isothermal amplification assay: a review of updated technology and future outlook. *Infect. Dis. Poverty*, **8**(1): 1-22.

Dixit, Y., Casado-Gavalda, M.P., Cama-Moncunill, R., Cama-Moncunill, X., Markiewicz-Keszycka, M., Cullen, P.J. and Sullivan, C. 2017. Developments and challenges in online NIR spectroscopy for meat processing. *Compr. Rev. Food Sci. Food Saf.,* **16**(6): 1172-1187.

Ferrara, M., Perrone, G., Gallo, A., Epifani, F., Visconti, A. and Susca, A. 2015. Development of loop-mediated isothermal amplification (LAMP) assay for the rapid detection of Penicillium nordicum in dry-cured meat products. *Int. J. Food Microbiol.*, **202**: 42-47.

Fletcher B., Mullane K., Platts P., Todd E., Power A., Roberts J., Chapman J., Cozzolino, D. and Chandra S. 2018. Advances in meat spoilage detection: A short focus on rapid methods and technologies. *CYTA J. Food*, **16**(1):1037-44.

Fu, X. and Chen, J. 2019. A review of hyperspectral imaging for chicken meat safety and quality evaluation: application, hardware, and software. *Compr. Rev. Food Sci. Food Saf.*, **18**(2): 535-547.

Garrido-Novell, C., Garrido-Varo, A., Pérez-Marín, D., Guerrero-Ginel, J.E. and Kim, M. 2015. Quantification and spatial characterization of moisture and NaCl content of Iberian dry-cured ham slices using NIR hyperspectral imaging. *J. Food Eng.*, **153**: 117-123.

Gopinath, S.C., Lakshmipriya, T. and Awazu, K. 2014. Colorimetric detection of controlled assembly and disassembly of aptamers on unmodified gold nanoparticles. *Biosens. Bioelectron. X*, **51**: 115-123.

Górska-Horczyczak, E., Guzek, D., Molęda, Z., Wojtasik-Kalinowska, I., Brodowska, M. and Wierzbicka, A. 2016. Applications of electronic noses in meat analysis. *Food Sci. Technol.,* **36**: 389-395.

Hardinge, P. and Murray, J.A. 2019. Reduced false positives and improved reporting of loop-mediated isothermal amplification using quenched fluorescent primers. *Sci. Rep.,* **9**(1): 1-13.

Hassoun A., Gudjonsdottir M., Prieto M. A., Garcia-Oliveira P., Simal-Gandara J., Marini F., Di Donato F., D'Archivio A. A. and Biancolillo A. 2020. Application of novel techniques for monitoring quality changes in meat and fish products during traditional processing processes: Reconciling novelty and tradition. *Processes (Basel)*, **8(**8): 988.

Hatakeyama S. and Akatsuka T. 2014. Measurements of gaseous peroxides in the oceanic lower atmosphere. *Western Pacific Air-Sea Interaction Study (Uematsu, M., Yokouchi, Y., Watanabe, YW, Takeda, S., Yamanaka, Y. Eds)*: 27-31.

He, H.J. and Sun, D.W. 2015. Microbial evaluation of raw and processed food products by Visible/Infrared, Raman and Fluorescence spectroscopy. *Trends Food Sci. Technol.*, **46**(2): 199-210.

Jia, W., Liang, G., Wang, Y. and Wang, J. 2018. Electronic noses as a powerful tool for assessing meat quality: A mini review. *Food Anal Methods*, **11***(*10): 2916-2924.

Kartakoullis, A., Comaposada, J., Cruz-Carrion, A., Serra, X. and Gou, P. 2019. Feasibility study of smartphone-based Near Infrared Spectroscopy (NIRS) for salted minced meat composition diagnostics at different temperatures. *Food Chem. X*, **278:** 314-321.

Kumar, Y., Bansal, S. and Jaiswal, P. 2017. Loop mediated isothermal amplification (LAMP): A rapid and sensitive tool for quality assessment of meat products. *Compr. Rev. Food Sci. Food Saf.*, **16**(6): 1359-1378.

Leng, T., Li, F., Chen, Y., Tang, L., Xie, J. and Yu, Q. 2021. Fast quantification of total volatile basic nitrogen (TVB-N) content in beef and pork by near-infrared spectroscopy: Comparison of SVR and PLS model. *Meat Sci.*, **180**: 108559.

Li, L., Mendis, N., Trigui, H., Oliver, J. D. and Faucher, S. P. 2014. The importance of the viable but non-culturable state in human bacterial pathogens. *Front Microbiol.,* **5**: 258.

Lucchi, N.W., Ljolje, D., Silva-Flannery, L. and Udhayakumar, V. 2016. Use of malachite green-loop mediated isothermal amplification for detection of Plasmodium spp. parasites. *PLoS One*, **11**(3): e0151437.

Nguyen, D.V., Nguyen, V.H. and Seo, T.S. 2019. Quantification of colorimetric loop-mediated isothermal amplification process. *Biochip J.*, **13**(2): 158-164.

Noorjahan, A., Aiyamperumal, B. and Anantharaman, P. 2019. Characterization and biochemical properties of Brown seaweed Sargassum tenerrimum (J. Aardh). *Int. J. Pharm. Biol. Sci.*, **9**(2): 350-357.

Peng, Y. and Wang, W. 2015. Application of near-infrared spectroscopy for assessing meat quality and safety. *Infrared Spectroscopy—Anharmonicity of Biomolecules, Crosslinking of Biopolymers, Food Quality and Medical Applications*.

Pereira Da Costa, M. and Conte-Junior, C.A. 2015. Chromatographic methods for the determination of carbohydrates and organic acids in foods of animal origin. *Compr. Rev. Food Sci. Food Saf.*, **14**(5): 586-600.

Picone G., De Noni I., Ferranti P., Nicolai M. A., Alamprese C., Trimigno A., Brodkorb A., Portmann R., Pihlanto A., El S.N. and Capozzi F. 2019. Monitoring molecular composition and digestibility of ripened bresaola through a combined foodomics approach. *Food Res. Int.*, **115**: 360-368.

Pothakos, V., Devlieghere, F., Villani, F., Björkroth, J. and Ercolini, D. 2015. Lactic acid bacteria and their controversial role in fresh meat spoilage. *Meat Sci.*, **109**: 66-74.

Rodriguez-Lazaro, D., Gonzalez-García, P., Gattuso, A., Gianfranceschi, M.V. and Hernandez, M. 2014. Reducing time in the analysis of Listeria monocytogenes in meat, dairy and vegetable products. *Int. J. Food Microbiol.*, **184**: 98-105.

Sirocchi, V., Caprioli, G., Ricciutelli, M., Vittori, S. and Sagratini, G. 2014. Simultaneous determination of ten underivatized biogenic amines in meat by liquid chromatography□tandem mass spectrometry (HPLC-MS/MS). *J. Mass Spectrom.*, **49**(9): 819-825.

Soglia, F., Silva, A.K., Lião, L.M., Laghi, L. and Petracci, M. 2019. Effect of broiler breast abnormality and freezing on meat quality and metabolites assessed by 1 H-NMR spectroscopy. *Poult. Sci.*, **98**(12): 7139-7150.

Taheri-Garavand, A., Fatahi, S., Omid, M. and Makino, Y. 2019. Meat quality evaluation based on computer vision technique: A review. *Meat Sci.*, **156:** 183-195.

Tao, F. and Ngadi, M. 2018. Recent advances in rapid and nondestructive determination of fat content and fatty acids composition of muscle foods. *Crit. Rev. Food Sci. Nutr.*, **58**(9):1565-1593.

Vasconcelos, H., Saraiva, C. and de Almeida, J.M. 2014. Evaluation of the spoilage of raw chicken breast fillets using Fourier transform infrared spectroscopy in tandem with chemometrics. *Food Bioproc. Tech.*, **7**(8): 2330-2341.

White, A.K., Heyries, K.A., Doolin, C., Vaninsberghe, M. and Hansen, C.L. 2013. High-throughput microfluidic single-cell digital polymerase chain reaction. *Anal. Chem.*, **85**(15): 7182-7190.

Wojnowski, W., Majchrzak, T., Dymerski, T., Gębicki, J. and Namieśnik, J. 2017. Electronic noses: Powerful tools in meat quality assessment. *Meat Sci.*, **131**: 119-131.

Wong, Y.P., Othman, S., Lau, Y.L., Radu, S. and Chee, H.Y. 2018. Loop-mediated isothermal amplification (LAMP): a versatile technique for detection of micro-organisms. *J. Appl. Microbiol.*, **124**(3): 626-643.

Wu, D., Wang, S., Wang, N., Nie, P., He, Y., Sun, D.W. and Yao, J. 2013. Application of time series hyperspectral imaging (TS-HSI) for determining water distribution within beef and spectral kinetic analysis during dehydration. *Food Bioproc. Tech.,* **6**(11): 2943-2958.

Wu, J., Peng, Y., Li, Y., Wang, W., Chen, J. and Dhakal, S. 2012. Prediction of beef quality attributes using VIS/NIR hyperspectral scattering imaging technique. *J Food Eng.*, **109**(2): 267-273.

Xiong, Z., Xie, A., Sun, D.W., Zeng, X.A. and Liu, D. 2015. Applications of hyperspectral imaging in chicken meat safety and quality detection and evaluation: A review. *Crit. Rev. Food Sci. Nutr.*, **55**(9): 1287-1301.

Yang, Q., Domesle, K.J., Wang, F. and Ge, B. 2016. Rapid detection of Salmonella in food and feed by coupling loop-mediated isothermal amplification with bioluminescent assay in real-time. *BMC Microbiol.*, **16**(1): 1-10.

Yang, Q., Domesle, K.J., Wang, F. and Ge, B. 2016. Rapid detection of Salmonella in food and feed by coupling loop-mediated isothermal amplification with bioluminescent assay in real-time. *BMC Microbiol.*, **16**(1): 1-10.

Zhang, H., Peng, Y., Wang, W., Zhao, S. and Dhakal, S. 2012. Non-destructive Detection of Water Content in Fresh Pork Based on Visual/Near-Infrared Spectrum. *Biol. Eng. Trans.,* **12**: 1.

Zhang, Z. 2017. Raman spectroscopic sensing in food safety and quality analysis: 1-16.

Zhao, M., Downey, G. and O'Donnell, C.P. 2014. Detection of adulteration in fresh and frozen beefburger products by beef offal using mid-infrared ATR spectroscopy and multivariate data analysis. *Meat Sci.*, **96**(2): 1003-1011.