J Food Sci Technol
https://doi.org/10.1007/s13197-022-05439-8

REVIEW ARTICLE

Recent technology for food and beverage quality assessment: a review

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Revised: 13 March 2022 / Accepted: 16 March 2022

Abstract Food and beverage assessment is an evaluation method used to measure the strengths and weaknesses of a food and beverage system to make improvements. These assessments had become crucial, especially in the issues of adulteration, replacement, and contamination that happened in artificial adjustment relating to the quality, weight and volume. Thus, this review will examine and describe features recently applied in image, odour, taste and electromagnetic, relevant to the food and beverages assessment. This review will also compare and discuss each technique and provides suggestions based on the current technology. This review will deliberate technology integration and the involvement of deep learning to enable several types of current technologies, such as imaging, odour and taste senses, and electromagnetic sensing, to be used in food evaluation applications for inspection and packaging.

Keywords Food and beverage assessment · Recent technology · Imaging technology · Odour and taste sensing technology · Electromagnetic sensing technology

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Introduction

Nowadays, food and beverage safety has been a global common health concern, especially in food hygiene and food quality. Food is a global necessity to consume every day for energy and development, health and disease prevention. Hence, it is important to ensure that only safe and qualified food products are supplied to consumers. However, in reality, consumers are facing difficulty in choosing the legal food products due to the poor quality of food, poor hygiene, food adulteration, food impurity, expired food and others issues.

Food adulteration is one of the major consumer issues in developing countries as it has a direct impact on human health. Food adulteration occurs due to decreased production costs and greater market demand than supply, especially for recent COVID-19 pandemic conditions. It is difficult for consumers to detect adulterated food through the human senses and can only go through laboratory equipment because the food has been substituted or mixed with other permitted or prohibited substances. Therefore, the development of food and beverage assessments is essential and should be a priority to ensure food safety and public health. Several methodological procedures and technologies have been developed for food and beverage assessment, including imaging, odour, taste, electromagnetic sensing, and others. (Abasi et al. 2018).

Examples of reviews in food quality analysis and detection of food adulteration include the analysis of meat and its products, milk, and fruits that have been introduced using several technologies. The imaging technologies, especially for hyperspectral imaging, are focused on the colour, shape and texture of substances. Odour and taste sensing technology (Quartz Crystal Microbalance (BAW), Metal Oxide Semiconductor (MOS-based electronic nose),

Published online: 18 April 2022

and Electrochemical biosensors are focused on the specific components of an aroma or solution and analyses their chemical composition by contact with its headspace and immersed in sample respectively, whereas electromagnetic sensing technology measures the electromagnetic wave transmission coefficient using the frequency, polarization, and angle of incidence of the electromagnetic wave, as well as the object's permittivity and conductivity. (Mustafa et al. 2019; Wei et al. 2018).

The motivation for this work originated from studying research papers in the area of technology integration, which stated that technology integration generally outperforms independent systems in terms of classification and quality evaluation. Thus, this work anticipates that signals from various techniques can be integrated using appropriate fusion and deep learning algorithms to provide results closer to mammalian sensory systems. This review will introduce the principles, advantages and disadvantages of the current in evaluating the quality of food and beverages, as well as the differences among this technique.

Assessment method using imaging technology

Imaging technology utilizes imaging processing technique to create or display two-dimensional or three-dimensional image. With the advancement of technology nowadays, the functionality of cameras and the clarification of image enable us to explore the external and internal structure of food products, which increase the accuracy and sensitivity in food quality analysis especially in agricultural-related rural products. Current food analysis devices which using imaging technology (as Fig. 1) including hyperspectral imaging, x-ray imaging, odour imaging as well as digital and analogue imaging devices.

Hyperspectral imaging (HSI)

HSI is a technique that combines spectroscopic and imaging approaches into a single system that provides both spectral and spatial data. HSI may use this combined technique to detect various components inside a product and measure their spatial distribution to compute the product's compositional gradient. HSI technique can scan a whole sample inside an image, capturing readings ranging from hundreds to millions of pixels (depending on sample size and camera spatial resolution), and calculating average nutritional values and/or a compositional gradient from these readings. (Tahmasbian et al. 2021).

HSI shows its abilities to analyse and predict food freshness (Suktanarak and Teerachaichayut 2017), chemical composition (Jamshidi et al. 2016; Barbin et al. 2013), and quality attributes (Kamruzzaman et al. 2016; Li et al. 2018). In food freshness, (Suktanarak and Teerachaichayut 2017) assessed the freshness of an egg by correlating a Standard HU value (using calculation on the weight of the egg and average height of the albumen) with the colour image captured by 900–1,700 nm Near-Infrared (NIR) hyperspectral imaging technique using Partial Least Square Regression (PLSR) model.

In chemical content, Barbin et al. (2013) constructed an experiment to determine the chemical composition of intact and minced pork using NIR hyperspectral imaging. This experiment used spectra extracted from hyperspectral image and perform the analysis using PLSR with a reference value of moisture, protein and fat contents from Smart Trac (CEM Corporation, Matthews, North Carolina, USA) and LECO FP-428 Nitrogen Determinator (LECO Instruments Ltd., Stockport, UK). In the detection of diazinon in pesticide residue on cucumber, Jamshidi et al. (2016) created a predictive model using PLSR algorithm to correlate the presence of pesticides and images captured by 450–1000 nm Visible Near-Infrared (VNIR) spectroscopy combined with chemometrics. The experimental results showed excellent execution of the framework planned in the assurance of pesticide residue and the overall health states of the cucumber grouping.

In quality attributes, Kamruzzaman et al. (2016) constructed a Multiple Linear Regression (MLR) model by choosing a set of feature wavelengths from a 400–1000 nm VNIR hyperspectral imaging system, which is aimed to correlate with the CIE L*a*b* colour space of fresh beef, lamb, and pork meat from the colourimeter. The integration of PLSR models (Li et al. 2018) with the image captured from 600–975 nm VNIR and 865–1610 nm short-wave infrared (SWIR) hyperspectral imaging to predict the plum quality in terms of colour *(L*, a* and b*)* and SSC.

HSI application showed potential in food and beverage quality assessment. However, the HSI application currently available in market are large size of the equipment, expensive, and difficult to manage and mostly used in laboratories. Furthermore, due to the design of mechanically moving components and frame rates limitation, the existing hyperspectral imaging cameras are only able to scan one line at a time. This limitation requires further study for better improvement especially in time usage (Schneider and Feussner 2017).

X-ray imaging

X-ray imaging is a non-contact sensor, which records the remaining of an x-ray beam transmission after passing through the body of an object. It's generally employed in medical diagnostics, item inspection, and even agricultural items to discover interior imperfections. Energy-dispersive X-ray fluorescence spectroscopy (EDXRF) is one of the

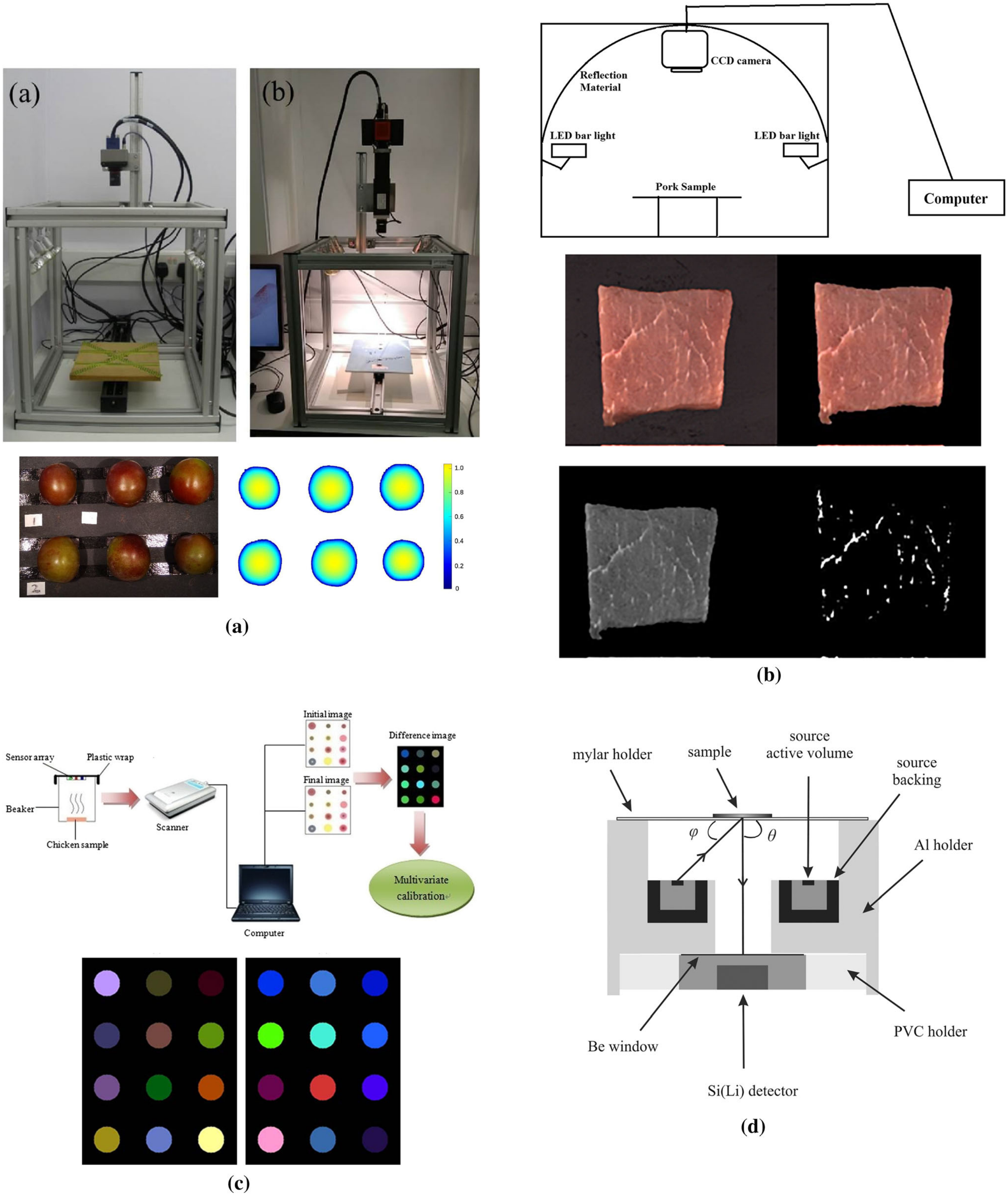


Fig. 1 Dedicated device based on Imaging Technology, that is including **a** Hyperspectral Imaging System with output mapping. (Li et al. 2018), **b** Colorimetric Sensor System with the output image. (Chen et al. 2014), and **c** Digital Imaging (Computer Vision) System with output processed image (Liu et al. 2018) **d** X-ray Imaging System (Papachristodoulou et al. 2018)

X-ray imaging technologies used to assess the quality of foods and beverages. It is used to determine the concentration of chemical elements such as K, Ca, Fe, Zn, Br, Rb, Cl, Cu, Mg, P, S, Se, Sr in milk powder (Rossmann et al. 2016; Papachristodoulou et al. 2018) and fat content in the green pork hams by combining Ultrasonic velocity (υ) and X-ray absorption (de Prados et al. 2015). Multivariate statistical methods, (Rossmann et al. 2016; Papachristodoulou et al. 2018) was used for close monitoring in milk powder production to ensure good manufacturing practices and stable infant formula quality.

Compared with conventional method, X-ray imaging technology is more effective in the detection of the metallic contaminant and other foreign non-metallic material such as bone, glass, wood, plastic, and rocks. The non-destructive features especially in viewing samples' interior features to detect hidden defects or contaminants make the X-ray imaging technology to become more popular. However, the usage of X-ray imaging technology require a relatively high cost and high voltage power supply, as well as the need of radiation shielding and the risks inherent in using radiation. (Haff and Toyofuku 2008).

Odour imaging

Currently, there is a cutting-edge technology for non-visible matter (odour) detection, which is an odour imaging-based colorimetric sensor array. The fundamental principle of odour imaging technology is based on colorimetric sensors, which utilizes the shading change brought about by the response between unstable substances and a progression of artificially responsive colours after chemo-responsive dyes (as main sensing unit of colorimetric sensor) detect and distinguish chemical vapours and then express response information in the form of imaging. The odour imaging-based colorimetric sensor array technology is comprised of a sensor array, a computer or controller, and a scanner. The sensor array acquired the sensor response value from the chemical vapour and converted it into colorimetric data. Before being processed by a computer or controller, the colorimetric data is transformed into an image using a scanner. (Rodríguez-Pulido et al. 2017).

There are several experiments conducted to prove the relationship between the concentration or presence of chemical vapour and food and beverage quality (Morsy et al. 2016; Chen et al. 2014, 2017; Bordbar et al. 2018). Firstly, colorimetric sensor array technique (Chen et al. 2014) is used to evaluate the freshness of chicken by using orthogonal linear discriminant analysis (OLDA) and adaptive boosting (AdaBoost) algorithm, namely AdaBoosteOLDA. Morsy et al. (2016) used non-destructive approaches and sensors for fish decay evaluation by assessing sixteen chemo-sensitive compounds (Alizarin, Bromocresol Green, Bromocresol Purple, Bromothymol Blue sodium salt, Bromophenol Blue, Xylenol Blue, Chlorophenol Red, Cresol Red, Crystal Violet Lactone, Reichardts dye, 2,6-dichloro-4-(2,4,6-triphenyl-1-pyridinio) phenolate, Phenol Red, Rosolic acid, Methyl Red, Curcumin and Carminic acid), mixes consolidated in a cluster for colorimetric recognition of common deterioration mixes (trimethylamine, dimethylamine, cadaverine, and putrescine). The experiment also effectively assessed the signal intensity recorded with the colorimetric exhibit according to fish decay time, as well as demonstrated the relationship between fish decay time and the adjustment of thiobarbituric acid, total volatile nitrogen, pH, and oxygen concentration. Next, Chen et al. (2017) developed a low-cost solution by repurposing the food's barcode as a colorimetric sensor cluster to monitor chicken aging and quality by using a smartphone camera. The experiment also collected the measurement of VOC from Nile red and Zn-TPP and pH from Methyl red and the result showed that colour change in pH and VOC responsive dyes are a clear indication of food aging under various temperature conditions. On the other hand, Bordbar et al. (2018) developed an alum and synthetic acetic acid detection and determination for fraud detection in pickle by using unsupervised by using unsupervised pattern recognition methods such as Principal Component Analysis (PCA) and Hierarchical Clustering Analysis (HCA) and PLSR through image analysis. This research showed the satisfied result by acquiring 0.469 and 0.446 for alum and also 1.34 and 0.933 for acidic corrosive in Root Mean Square Error for adjustment and expectation respectively.

As a summary, the colorimetric sensor array based on odour imaging can detect some analytes effectively. This technology has the potential for mass production and deployment due to its ease of fabrication, lightweight and compact and easy integration with cameras. However, it is difficult to analyse large data sets of RGB values to classify the individual components of a mixture. (Kangas et al. 2016).

Digital and analogue image processing

Computer Vision System (CVS) is a framework that incorporates a lighting arrangement, camera, and image investigation programming utilizing a PC. It has been widely used in the food industry and as it is known to be quick, prudent, steady, precise and non-intrusive (Husin et al. 2012; Zareiforoush et al. 2016). Numerous undertakings have been made to expand the utilization of CVS in the agricultural field, such as spicy powder quality assessment (Shenoy et al. 2015), red meat colour, marbling score (Sun et al. 2018), imperfection (Chmiel and Słowiński 2016) and intramuscular fat rate (IMF%)

prediction and quality evaluation (Liu et al. 2018). (Liu et al. 2018) used stepwise regression and support vector machine models to estimate pork intramuscular fat rate (IMF%) by collecting RGB, HSI, and L*a*b* colour space, and the accuracy results were obtained 0.63 and 0.75 for regression models and support vector machine, respectively. (Sun et al. 2018) had developed a CVS to determine the colour and marbling score of pork loin using vector machine forecast model and obtained the prediction accuracy of 92.5% and 75.0%, for measured colour and marbling score respectively. (Chmiel and Słowiński 2016) had proven the usefulness of CVS to distinguish meat imperfections of m. longissimus lumborum (LL) by measuring the colour of the meat in CIEL*a*b* and obtained the highest accuracy of 82.6%. According to (Shenoy et al. 2015), digital colour imaging method (DCI)can be used for assessing the mixture quality of spice powder, as it showed a good trend with the salt concentration method where there is colour difference between the powders.

CVS able to extract various characteristics, such as colour, image texture, shape and scale. With accuracy, objectivity and speed, these simple appearance characteristics allow task-relevant analysis and interpretation. These appearance characteristics can correlate well with several physical, chemical and sensory food quality indicators. These quality attributes are often related to characteristics that can be assessed directly by non-destructive frameworks. Since quality features are related to physicochemical properties, several methods of image processing have been developed, making a significant contribution to the industrial requirements for automated inspection and grading. However, higher resolutions and faster processing of features are needed for digital image processing, since a large amount of data needs to be processed in a short period or in real-time. (Valous and Sun 2012).

Assessment method using odour and tasting sensing technology

The sensation of smell and taste is one of the analytical tools used in food industry for the early detection of quality changes in food products. However, the cost of hiring tangible professionals is high and limited by the fact that our sense of smell and taste is subjective and gets tired easily. Different confinements of tangible evaluation incorporate the reproducibility of the outcomes and low reproducibility, which makes tangible evaluation impossible to provide quantitative research (Majchrzak et al. 2018). As such, is absolutely necessary to have an instrument that can mimic the human sense of smell and taste and to be used in routine industrial applications. Gas chromatography is one of the great inventions used to determine the physicochemical properties of products. In order to promote this technology to industrial application, several instruments are created for the purpose of quality evaluation of food and beverages as shown in Fig. 2. (Peris and Escuder-Gilabert 2016).

Metal-oxide semiconductor (MOS)

This MOS has been more widely used to make arrays for odour measurement than any other class of gas sensors. It has a gas-sensitive film consisting of tungsten oxide or tin oxide. The most widely used material in the film is tin dioxide (SnO_2) doped with a small amount of a catalytic metal such as palladium or platinum. When the gas (oxygen) reaches the sensor under normal circumstances, the gas reacts and is absorbed into the film and combines with electrons, thus causing the blocking of electron flow and the sensor remains unpowered. However, in the presence of a reducing gas, the gas (oxygen) is absorbed by the gas molecules, resulting in zero electron attraction, resuming the electron flow and activating the sensor. Also, by changing the choice of catalyst and operating conditions, tin dioxide resistive sensors have been developed for a range of applications, especially in food and beverage assessment. Food and beverage normally released several volatile organic compounds (VOCs) that belong to certain chemical groups such as sulphur and aliphatic (methane, ethane, propane and butane). By using the MOS abilities and characteristics of VOCs from food and beverage, several kinds of research have been accomplished performing food and beverage assessment, in terms of freshness (Wijaya et al. 2017; Du et al. 2015), classification (Heidarbeigi et al. 2015), and content prediction (Li et al. 2016).

In classification, (Heidarbeigi et al. 2015) used electronic nose to classify various kinds of saffron. A sensor array of six MQ-type metal oxide semiconductors (HANWEI Electronics Co., Ltd., Henan, China) is used in the electronic nose and the sensor data collected from a data acquisition card (NI USB-6009, National Instrument), for classification purpose (PCA and Backpropagation Neural Network, BPNN). The experiment result showed that 86.87% success rate among classification of saffron and different percentage mixture with dyed corn stigma and yellow style, and 100% success rate between classification saffron and different percentage of safflower, using BPNN algorithm. In content prediction, (Li et al. 2016) implemented pork freshness with different packaging methods using PEN3 E-nose (an array of 10 different metal oxide sensors) together with PCA and MLR algorithm to correlate the total viable counts (TVC) and total volatile basic nitrogen (TVBN). This study showed that the increase of TVBN in meat samples is related to the decomposition

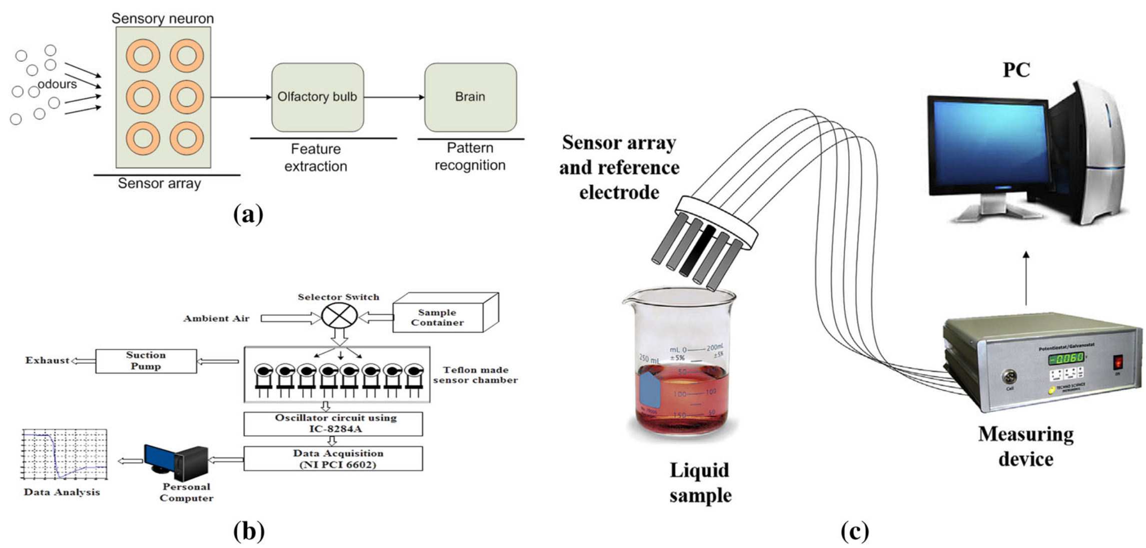


Fig. 2 Dedicated device based on odour and taste Technology, that is including **a** Metal Oxide Semiconductor System (Wijaya et al. 2017), **b** Quartz Crystal Microbalance Sensor System (Debabhuti et al. 2019), and **c** Electrochemical sensor System (Di Rosa et al. 2017)

activity of spoilage bacteria and endogenous enzymes, which is producing many volatile organic compounds such as alcohols, ketones, hydrogen sulfide, aldehydes, and organic acid.

In freshness, a portable electronic nose device system was developed by (Wijaya et al. 2017), to monitor the beef freshness which consist of a combination between 10 MQ-type gas sensors and Arduino Mega SDK microcontroller and K-Nearest Neighbour algorithm. The experimental results showed the system is perfectly distinguished fresh and spoiled beef by achieving classification accuracy for binary, three classes, and four classes classification with 93.64%, 86.00%, and 85.50%, respectively. (Du et al. 2015) employed six tin oxide sensors (Figaro Engineering Inc.) with PCA and Fisher Linear Discriminant as the classifier to determine shrimp freshness. The sensory evaluation and the content of Total Volatile Basic Nitrogen (TVBN) were performed to indicate the freshness of the shrimp and the result showed that the discriminant rates were 98.3% for 120 modeling sample data, and 91.7% for 36 testing sample data.

The utilities of MOS sensor in food and beverage assessment is high, due to its high sensitivity to chemicals in a wide range of VOCs, reliability, and reproducibility. However, its ability to operate in high temperature require more power supply, and make it susceptible to humidity which makes it to prone to drift. (Örnek and Karlik 2012).

Quartz crystal microbalance (QCM)

QCM is a highly sensitive mass sensing technique that can detect changes in mass in the nanogram range. This means that QCM sensors can detect changes in mass as tiny as a fraction of a monolayer or a single atom layer across sensor crystal. High sensitivity and real-time monitoring of mass changes in sensor crystal make QCM an attractive method for gas sensors. Several researchers employed QCM sensors to collect volatile gas data for food and beverage assessment, in terms of freshness (Mohareb et al. 2016) and classification (Kodogiannis 2018; Sharma et al. 2015; Debabhuti et al. 2019).

In freshness assessment, (Mohareb et al. 2016) constructed efficient tools for beef freshness to correlate the population of selected microbial groups, namely total viable counts (TVC), Pseudomonas spp., B. thermosphacta, Enterobacteriaceae, and lactic acid bacteria, to the responses of the electronic nose sensors from an electronic nose (LibraNose, Technobiochip, Napoli, Italy), sensory score and Ensemble-based support vector machines algorithm (bagging and boosting). The result showed that overall prediction was also increased in the case of regression models for bacterial species count prediction from 76.5% to 85.0%.

In classification, (Kodogiannis 2018) distinguished fresh, semi-fresh, and spoiled beef using a QCM sensor (Libra enose, eight 20-MHz AT-cut quartz crystal microbalances positioned in a measurement chamber) and a Multi-Input Multi-Output (MIMO) Clustering Fuzzy Wavelet Neural Network (CFWNN). The result showed that the model overall achieved a 95.7% correct classification, and 100%, 87.5% and 100% for fresh, semi-fresh and spoiled meat samples, respectively. (Debabhuti et al. 2019) and (Sharma et al. 2015) used six and eight QCM sensors respectively to collect the aroma released by mango and black tea and the sensor output is checked progressively utilizing NI PCI6602 data acquisition card as well being stored in the personal computer. Research results on black tea fermentation and mango maturity using the PCA algorithm showed that the QCM sensor cluster is suitable for real-time, field-deployable and accurate techniques to observe the maturity stage of mango and aging time of black tea.

The popularity of QCM sensor in food and beverage assessment was due to its high accuracy, detection of wide range of active element and low cost of production. However, the QCM sensor consists of complicated electronics with high sensitivity, poor signal-to-noise ratio, humidity and temperature sensitivity. (Guz 2019).

Electrochemical sensor

The electronic tongue or electrochemical sensor is a taste sensor system linked to the model recognition apparatus to analyse the complex fluid media, such as food and beverages. The techniques used in electrochemical techniques included potentiometry (Zhang et al. 2015) and cyclic voltammetry (Pauliuc et al. 2020; Li et al. 2015; Apetrei and Apetrei 2016).

The potentiometry method is implemented for measuring the potential between two electrodes in the absence of current. The measured potential can be utilised to identify the analyte of interest, especially on the concentration of particular solution components. (Zhang et al. 2015) implemented the TS-5000Z electronic tongue sensor system (Insent Inc., Japan, consisting of a bitterness sensor (SB2C00), umami sensor (SB2AAE), saltiness sensor (SB2CT0), sourness sensor (SB2CA0), and astringency sensor) and PCA algorithm to evaluate meat quality based on taste assessment, recognition and correlation with meat chemical composition. The result showed that fat content had the highest positive correlation with sourness ($r = 0.8002$, $P < 0.001$) while was negatively correlated with umami ($r = -0.9086$, $P < 0.001$) and saltiness ($r = -0.8197$, $P < 0.001$).

A voltammetry method collects the Faradic current and capacitive current when the electrodes are immersed in the tested solution and there are compounds in the solution that are electrochemically active at the applied potential. The voltammetry method has been used in a variety of studies in food and beverage evaluation, including milk adulteration, honey authentication, and ammonia detection. (Apetrei and Apetrei 2016) created a Partial Least Squares-Discriminant Analysis (PLS-DA) model to detect putrescine and ammonia in beef samples using data from the Biologic SP 150 potentiostat/galvanostat (Bio-Logic Science Instruments SAS, France). The validation of the PLS-DA model was performed using the leave-one-out fully cross-validation method, obtaining in all cases more than 96% levels of correct classification with higher than 97% sensitivities and more than 96% specificities. The PCA model was built by (Pauliuc et al. 2020) and (Li et al. 2015) to authenticate Romanian honey and examine the milk contamination with urea, respectively using data from the voltammetric electronic tongue (electrochemical station CHI660E, Shanghai Chenhua Organization; PGSTAT 204 with FRA32M module, Metrohm, Filderstadt, Germany). The studies demonstrated the capability of the voltammetry technique to perform a quick representation of urea-corrupted milk segregation and nectar test. (Kundu et al. 2019).

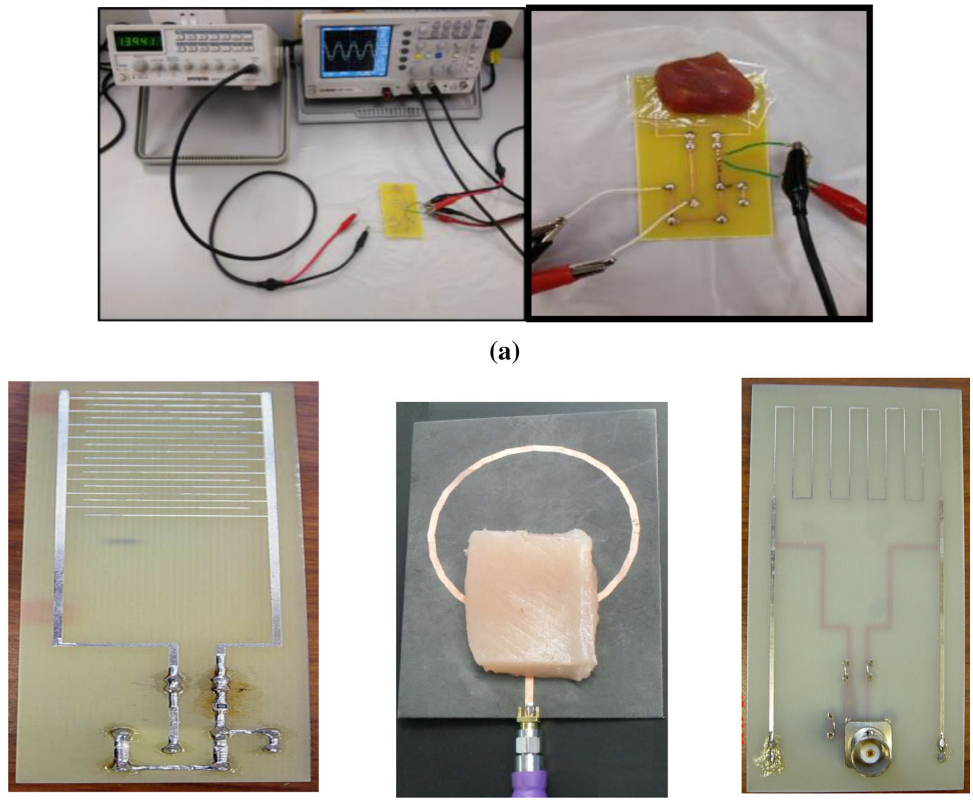
Electrochemical sensors have shown their potential advantages in food and beverage assessment, including high accuracy and high sensitivity to chemical constituents, together with low power consumption. However, the ability of electrochemical sensor decreases with time due to the degradation of the electrode catalyst and eventually polluted in-process applications by process gases. Moreover, the electrochemical sensor only operates with a limited temperature range and has mild selectivity. (Manjavacas and Nieto 2016).

Assessment method using electromagnetic sensing technology

This electromagnetic sensing technology depends on a planar electromagnetic sensor with radio recurrence excitation and utilized PC for calculation to achieve online quality monitoring. Planar electromagnetic sensing is a non-destructive technique and evaluation based on inductive, capacitive or electromagnetic approaches, which depends on material dielectric properties as well as the electrode and material geometry affect the capacitance and the conductance between the two electrodes. This characteristic is gaining popularity in several applications, including material permittivity analysis, gas detection, and even food inspection. Online sensing systems suitable for the food and beverage industry need to have some key characteristics and qualities to meet the requirements, including cost feasibility, high reliability in terms of estimation accuracy and estimation speed. At the same time, the sensor technology must be able to estimate volumetric permeability in order to measure performance throughout the product, which can be achieved by using planar electromagnetic detection technology as shown in Fig. 3 (Gooneratne et al. 2005). The example of planar electromagnetic sensing technology is planar interdigital sensing, planar meander sensing, and planar microstrip ring sensing.

In planar interdigital sensing, (Mukhopadhyay and Gooneratne 2007) developed a non-destructive novel interdigital biosensor for measuring fat content in pork using the characteristics of the generation of AC source and

Fig. 3 Dedicated device based on electromagnetic sensing Technology, that is including **a** Experimental setup for food analysis(Abdullah et al. 2016), **b** planar Interdigital sensor design (Mukhopadhyay and Gooneratne 2007), and **c** planar microstrip ring sensor design (Jilani et al. 2014) and **d** planar meander sensor design (Gooneratne et al. 2005)



(b) (c) (d)

electromagnetic field generated from two electrodes. The experiment also conducted a reference analysis for fat content analysed by Soxhlet extraction of the homogenized sample (including the skin) using petroleum ether and the result showed that they are quite distinctive among different parts of pork meat in terms of impedance value. In sugar content measurement, (Siriporn et al. 2018) compared the measurement from a planar interdigital sensor with the readings on a refractometer and the results showed that correlation coefficient (R^2) was obtained at 0.9805.

In microstrip ring sensing, (Jain and Mishra 2019) microstrip ring dampness sensor was used in determining the moisture of rice grain by utilizing stove drying technique and measured by the vector network analyzer (Model No. Field fox N9925A). (Jilani et al. 2016) also successfully proposed a solution for determining the moisture of broiler chicken meat using microwave ring resonator sensor and measured by using Anritsu MS2034B vector network analyzer over the range of 0–4 GHz, which is showing the significant changes when the corresponding

Table 1 Comparison between electronic senses, sensory analysis and conventional laboratory instruments features. (Di Rosa et al. 2017)

Feature	Imaging technology	Odour sensing technology	Taste sensing technology	Electromagnetic sensing technology
Rapidness	Yes	Yes	Yes	Yes
Low-cost analysis	Yes	Yes	Yes	Yes
Use of chemicals	No	No	No	No
Objectiveness	Yes	Yes	Yes	Yes
Non-destructive measurements	Yes	Yes	No	Yes
Sample pre-treatment	No	No	Yes	No
Simplicity	Yes	Yes	Yes	Yes
Single operator	Yes	Yes	Yes	Yes
Permanent storage of data	Yes	Yes	Yes	Yes

Table 2 Application of dedicated devices on food assessment

Food	Technology	Methods	Purpose of analysis	Target	Reference
Beef	Imaging	Hyperspectral Imaging	Visualizing variations in quality attributes in beef samples using PLSR model by developing image processing algorithms	Colour ($L^*a^*b^*$), pH and tenderness	(ElMasry et al. 2012)
	Odour and Taste	Metal Oxide Semiconductor (MOS)	Meat quality monitoring and detection by introducing the development of mobile e-nose (MoLen) and the prospective applications	Freshness	(Wijaya et al. 2017)
		Quartz Crystal Microbalance (QCM)	Analyse by using multi–input–multi–output (MIMO) clustering-based fuzzy wavelet neural network (CFWNN) system to volatile fingerprints of odour profile with beef spoilage	Spoilage	(Kodogiannis 2018)
		Quartz Crystal Microbalance (QCM)	Tackle this issue through the improvement of a progression of gathering based classifiers and relapse models utilizing bolster vector machines and electronic nose datasets	Freshness	(Mohareb et al. 2016)
		Electrochemical (Potentiometry)	Survey the capacity of electronic tongue sensor framework TS-5000Z as a fast-systematic apparatus to assess the beef quality through flavour evaluation, acknowledgment and substance pieces as per its relationship with flavour	Flavour assessment, recognition and chemical compositions	(Zhang et al. 2015)
		Electrochemical (Voltammetry)	Created, described and utilized voltammetric sensors dependent on carbon changed by bisphthalocyanines and polypyrrole doped with different dopants for the recognition and measurement of putrescine and alkali	Ammonia putrescine	(Apetrei and Apetrei 2016)
	Electromagnetic Sensing	Planar Meander	To differentiate between beef and pork meat by method of non- destructive investigation	Type of meat	(Abdullah et al. 2016)
		Planar MEFSs	Testing the ability of measuring the fat content by conducting a series of experiments	Fat content	(Rittscher et al. 2018)
Chicken	Imaging	Odour Imaging	Evaluation of chicken freshness using AdaBoosteOLDA algorithm using a novel colorimetric sensor array development	Freshness	(Chen et al. 2014)
		Odour Imaging	To monitor gases emanating from the food inside the package environment as an indirect indicator of its condition using optical dyes to serve as an optical sensor	Spoilage	(Chen et al. 2017)
	Electromagnetic Sensing	Planar Meander	Design of another sort of microwave sensor having a high affectability for dielectric portrayal of natural tissues displaying high complex dielectric consistent	Characterization	(Tlili et al. 2018)
		Planar microstrip ring sensing	Increment of sensitivity of a resonator	Characterization	(Jilani et al. 2014)
Pork	Imaging	Hyperspectral Imaging	Identification of most significant wavelengths using PLSR model that are highly linked to the chemical composition studied	Protein, moisture and fat contents	(Barbin et al. 2013)
		Digital and Analogue Imaging	Research on the ability of computer vision systems to predict the percentage of pork intramuscular fat (IMF%)	Pork intramuscular fat percentage (IMF%)	(Liu et al. 2018)
		Digital and Analogue Imaging	Build up a computer vision system (CVS) for target estimation of pork midsection under industry speed prerequisite	Colour score and marbling score	(Sun et al. 2018)

Table 2 continued

Food	Technology	Methods	Purpose of analysis	Target	Reference
		Digital and Analogue Imaging	Decide the viability of computer vision system (CVS) to identify meat imperfections of m. longissimus lumborum (LL) in mechanical settings	Colour (CIEL*a*b*)	(Chmiel and Słowiński 2016)
		X-ray Imaging	Analyse the ability of ultrasound and DEXA strategies to anticipate both independently and mutually the fat substance of green hams	Fat content	(de Prados et al. 2015)
	Odour and Taste	Metal Oxide Semiconductor (MOS)	Evaluate the newness of chilled pork during capacity utilizing extraordinary bundling techniques, including pallet packaging (PP), vacuum packaging (VP), and modified atmosphere packaging (MAP, 40% O2/40% CO2/20% N2)	Total viable counts (TVC) and total volatile basic nitrogen (TVBN)	(Li et al. 2016)
	Electromagnetic Sensing	Planar Meander	Plan the sensor was in a manner to build high handle district at the split and reduction the working recurrence because of augmentation of capacitance esteem	Adulteration	(Abdullah et al. 2016)
Lamb	Imaging	Hyperspectral Imaging	Evolve quantitative functions utilizing Multiple Linear Regression (MLR) for online prophecy	Colour (L*, a*, b)	(Kamruzzaman et al. 2016)
Fish	Imaging	Odour Imaging	Propose for observing of the procedure the use of a sensor exhibit made out of various chemo-delicate mixes as opposed to single or a couple of mixes	O_2 level and pH, TVB-N, TBA contents, and microbial growth	(Morsy et al. 2016)
Cucumber	Imaging	Hyperspectral Imaging	Build up a spectroscopic system for quick and non-damaging wellbeing control of horticultural products dependent on nonappearance/nearness of pesticide deposits with a contextual analysis on diazinon identification and assurance in cucumber	Pesticide residues	(Jamshidi et al. 2016)
Egg	Imaging	Hyperspectral Imaging	Decide the capacity to gauge the newness of hens' eggs and to contrast the technique and the standard HU test	Freshness	(Suktanarak and Teerachaichayut 2017)
Plum	Imaging	Hyperspectral Imaging	Design PLSR models for the forecast of colour parts (L*, a* and b*), solidness and SSC of plum for the cultivars alone and in combination	Colour, firmness and soluble solid content (SSC)	(Li et al. 2018)
Fruit pickle	Imaging	Odour Imaging	Demonstrate amazing potential for subjective and quantitative control of natural product pickle samples	Adulteration	(Bordbar et al. 2018)
Spice Powder	Imaging	Digital and Analogue Imaging	Explore the capability of the DCI technique for surveying blend nature of flavour powders by contrasting it and a salt conductivity strategy	Quality of food powders	(Shenoy et al. 2015)
Dairy Product	Imaging	X-ray Imaging	Decide the mineral creation of business new-born child milk formulae utilizing Energy-Dispersive X-Ray Fluorescence (EDXRF) spectrometry, to contrast the deliberate qualities and the comparing esteems named by producers and with those portrayed in the European enactment	Mineral composition of commercial infant milk	(Papachristodoulou et al. 2018)
		X-ray Imaging	Examine capacities of another spectrometer Shimadzu EDX-7000 for the spectroscopic assurance of synthetic component substance in milk items and improvement of satisfactory methods for an exact assurance of accessible concoction	Chemical element contents in milk products	(Rossmann et al. 2016)

Table 2 continued

Food	Technology	Methods	Purpose of analysis	Target	Reference
			component substance in milk items utilizing this gadget		
	Odour and Taste	Electrochemical (Voltammetry)	Build up a quick, cheap, and exact investigation strategy dependent on non-changed anodes for the subjective examination of milk tainted with urea	Adulteration	(Li et al. 2015)
Saffron	Odour and Taste	Metal Oxide Semiconductor (MOS)	Study the viability of a system for recognizing unique saffron from safflower (Carthamus tinctorius L.) as the most significant debased material in saffron, saffron with yellow style, saffron marks of disgrace overwhelming with corn shame (called silk) hued utilizing normal colours, for example, beetroot (Beta vulgaris L.) in light of e-nose innovation	Adulteration	(Heidarbeigi et al. 2015)
Shrimp	Odour and Taste	Metal Oxide Semiconductor (MOS)	Build a model to foresee newness of shrimp utilizing PCA and Fisher Direct Discriminant	Freshness	(Du et al. 2015)
Mango	Odour and Taste	Quartz Crystal Microbalance (QCM)	Separate the development level of various cultivars of mangoes utilizing QCM based E-nose and PCA	Maturity	(Debabhuti et al. 2019)
Black Tea	Odour and Taste	Quartz Crystal Microbalance (QCM)	Research the QCM sensor cluster based electronic nose in distinguishing the ideal aging time of same tea samples	Fermentation	(Sharma et al. 2015)
Sugarcane juice	Electromagnetic Sensing	Planar Interdigital	Propose instrument development for estimating the sugar content in sugarcanes juice	Sugar content	(Siriporn et al. 2018)
Honey	Odour and Taste	Electrochemical (Voltammetry)	Approve the outcomes got with a voltammetric electronic tongue for nectar samples from Romania with those gave by melissopalynological analysis	Characterization	(Pauliuc et al. 2020)
Rice Grain	Electromagnetic Sensing	Planar microstrip ring sensing	Proposed another microstrip ring dampness sensor for deciding the dampness of rice grains utilizing the stove drying strategy	Moisture	(Jain and Mishra 2019)

capacitance decreases 30% in the early ageing (0D–7D) period.

For planar meander sensing, (Abdullah et al. 2016) proposed a detecting adulteration system that can differentiate between beef and pork meat. The experiment is collected S21 measurement and impedance for different parts of beef and pork and the result showed that the pork has a higher value of S21 (dB), higher resonance frequency (2.76 GHz) and impedance (Ω) compared to beef.

The ability of electromagnetic sensing technology including capacitive and dielectric properties to investigate functional relationships with impedance, frequency, fat content, soluble solid content, moisture content and other processing parameters would greatly useful in food and beverage quality assessment. This technology's responsiveness to structural alterations that may emerge during heating or other physical interactions should be improved because of the size of the detected sample or the various samples needing distinct structural designs. (Khaled et al. 2015).

Conclusion and future trends

As can be seen from the above studies, it is noted that the technology used in food and beverage assessment still requires further research to investigate and study the more specific elements that could be used to improve the quality of evaluation. It is critical to prevent food adulteration as a result of inadequate food supply for the increasing population. Recently, people pay more and more attention to food and beverage quality, which urge the demand of dedicated portable non-destructive equipment. The characteristics of low cost, lightweight, user-friendliness and quick inspection are particularly concentrated in such instruments A survey of the literature indicates that researchers have recently begin to design and develop portable and/or handheld devices on food and beverage assessment. Artificial intelligence technology was encouraged to incorporated into detection technologies in order to reduce the human resource and human error.

It should be pointed out that the recommendation made for the integration between image, odour, taste and electromagnetic technology using appropriate fusion and deep learning algorithm that can provide results closer to mammalian sensory systems for the food and beverage assessment. It is because each method acts as a part of the human body, just as the imaging method acts as the human eye, the smell method acts as the human sense of smell, followed by the taste method acts as the human tongue. Last, the electromagnetic effect acts like human skin. Each method has its own advantages and disadvantages. Each method has its own advantageous and disadvantageous as shown in Table 1. When one of the methods failed to perform, there are still other methods can perform to cover the fault. A decision-making system is necessary to make the right decision to perform the collaborative between each technique. Currently, deep learning is a promising technique, which the performance is much better than machine learning. The deep learning applications use a layered structure of algorithms called an artificial neural system, which is motivated by the organic neural system of the human mind, prompting a procedure of discovering that is unmistakably more able than that of standard AI models. The summary of this review article is presented in Table 2.

Acknowledgements The authors acknowledge the financial support from Universiti Malaysia Perlis (UniMAP) and Ministry of Higher Education Malaysia under the Fundamental Research Grant Scheme (FRGS) number: FRGS/1/2019/TK04/UNIMAP/02/7.

Authors' contributions WKT: conceptualization, investigation, software, writing—original draft. MLY methodology, writing—review and editing, investigation. MAHI: visualization, investigation. ZH: validation, Writing—review and editing, Supervision.

Funding We acknowledge the financial support from the Ministry of Higher Education Malaysia under the Fundamental Research Grant Scheme (FRGS) number: FRGS/1/2019/TK04/UNIMAP/02/7; all of which enabled us to carry out this study.

Code availability Not applicable.

Availability of data and material Not applicable.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethics Approval Not applicable.

Consent to Participate Not applicable.

Consent for Publication Not applicable.

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