Role of Analytical Techniques in Food Quality Control and Safety

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Abstract

Food quality control and analysis have many attributes that are discussed in this chapter. Quality and safety are the major parameters in any food industry, the importance of which is discussed in this chapter. Food analysis involves various steps along with different methods, the selection of which depends on various factors such as composition of food product which are mentioned in this chapter. The brief overview of different analytical techniques including sample preparation techniques, general analysis techniques, determinative and separation techniques, biological techniques, rheological techniques, radiochemical and electrochemical techniques, and their selection methods are also discussed in this chapter.

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12.1 Quality and Safety

Food is any product or substance, which when eaten by human or animals provides them energy in the form of nutrition. It is considered to be the most important and basic need of any living being, which comes prior to other basic needs like clothing and shelter. Food, when consumed serves various functions in body, such as it is responsible for body's maintenance, growth, repairment as well as reproduction (Rajput et al. 2019). Thus, quality along with the safety of food is among the crucial parameters for underdeveloped, developing, and developed economies. The quality of food determines its characteristics which are desirable and are acceptable among the customers. These characteristics can be chemical, physical, sensory (e.g. smell, taste) or convenience (e.g. steps in preparation). Therefore, it can be undoubtedly stated that the term food quality applicable over broader range than food safety. Hazard free or food safety is one of the most important parameter of the food quality system. Setting up the measures to achieve consistent quality is not just an option in any industry but every batch must reach up to the quality standards as set by the industries, thereby maintaining the consistency in quality. These systems somehow are mandatory by law while some are implemented voluntary by the members of food chain in industry (Sikora and Strada 2005).

Nowadays, consumers are exposed to diversified range of food products due to increased international trade of different food products, as a result of which, the consumers are getting prone to various risks associated with food safety. Thus, FSMS (Food Safety Management System) which includes GMP (Good Manufacturing Practices), HACCP (Hazard Analysis Critical Control Points), and GHP (Good Hygiene Practices) needs to put proper vigilance over the food hygiene and its supply. In recent years, the trend for implementation of these systems has come into existence in different countries. Despite this, the public health issues are still prevailing and are continuously arising along with other food-borne diseases. These food-borne diseases generally produce symptoms related to gastro-intestinal, the severity of which may result in organ failure or may cause cancer (Oldewage-Theron and Egal 2016). These food-borne diseases have emerged as a global health challenge for public due to various reasons. While the former diseases are cured from time to time but the new threats emerge continuously. Also, due to increased length of food supply chain and its globalization, various food items are available throughout the world, which in turn is responsible for spreading of pathogens to various geographical regions, and therefore the consumers get exposed to such unfamiliar food-borne diseases in such a new environment. Besides this, changes in microorganisms in different environment have led to evolution of novel pathogens which are resistant to antibiotics. The food usually prepared outside the home in poor

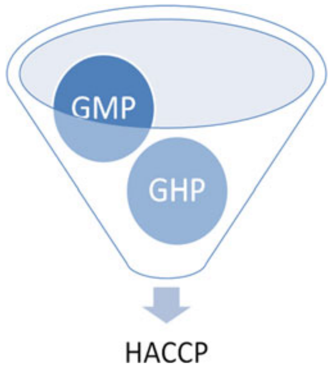

Fig. 12.1 Diagram illustrating the relationship between GHP, GMP, and HACCP (Sikora and Kołożyn-Krajewska 2001)

hygienic conditions poses greater risk for causing the food-borne diseases (WHO 2008). Thus, there is an urgent need to establish the reliable sanitary-surveillance system for identification of risk analysis, potential hazards and to control the spread of food-borne disease (Camino Feltes et al. 2017). However, majority of government across the globe are concerned for the persisting issues of food-borne diseases and are putting their efforts to solve this problem.

Protection of the consumer is the most important parameter and ultimate goal of any food industry in terms of its quality control and in order to ensure these protocols in terms of consistency and reliability. Several sets of laws, rules, and regulations have been made which covers different acts that affect the market in one form or the other. As discussed above, these include HACCP, GMP, GHP, along with various federal laws, regulations, and regular inspections related to factory, import, and export. These systems comprise of systematic approach which assures the particular traits of food product at particular stage of manufacturing, production as well as distribution.

GMPs or good manufacturing practices are the set of regulations that are to be followed and must be fulfilled during the manufacturing process that assures the safety of the food being produced. In a similar way, GHPs or good hygienic practices are the set of regulations that are to be followed to maintain proper hygienic conditions which should be monitored during all the steps of food chain and this in turn assures the safety of food. The prerequisites of good manufacturing practices and good hygienic practices when incorporated together forms another broader term related to food safety assurance system, called HACCP or hazard analysis and critical control point, the relation of which can be illustrated through Fig. 12.1. HACCP is a systematic method which assures food safety. It functions by identification, evaluation, and controlling the food hazards. It acts as a tool for the safety and management of product, which is further, linked with various management systems as given in Fig. 12.2. The complete HACCP system includes overall 12 stages, which is further composed of 7 principles and 5 preliminary tasks, which are as follows:

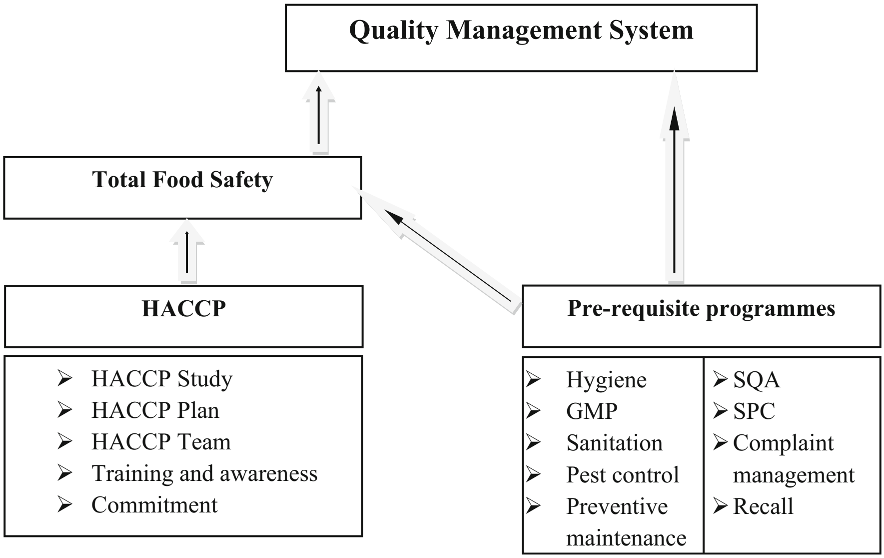

Fig. 12.2 Food safety within the QMP (Quality management programme)

12.1.1 Principles of HACCP

- Conduct hazard analysis.
- Determination of CCP, i.e. critical control point.
- Establishing the critical limits.
- Establishing the monitoring protocols.
- Establishing the corrective actions.
- Establishing the verification protocols.
- Documenting and record keeping.

12.1.2 Preliminary Tasks of HACCP

- Assembling of HACCP team.
- Food description and distribution.
- Description regarding the intended use of food to the consumer.
- Developing the flow diagram describing the process.
- Verification of flow diagram.

Several parameters are taken into consideration and are evaluated by various instruments to ensure the proper quality of the food products, viz. physico-chemical parameters, rheological parameters, phytochemical parameters, and packaging materials.

12.2 History of Utilization of Analytical Techniques in Food Quality Control and Safety

Since 2500 years back, prevention of meat and meat products was done by Egyptian and Mosaic laws. At the same time around 2000 years back, countries like India had established the regulations for pro by Egyptian and Mosaic laws. At the same time around 2000 years back, countries like India had established the regulations for prohibiting adulterations in fats and grains. It was mentioned in the books of *Old Testament* to restrict the consumption of the meat of such animals which were not slaughtered and died of unnatural cause. Regulated weights were used for measurement purposes. As per the records mentioned by Lasztity et al. (2004), wines were inspected and control on beers was done just to ensure the purity and quality of these commodities. Roman government had strict control over the supplies of food and helps the customers to prevent themselves from fraudulence and bad quality. However, it was still observed that during scarce conditions, there was resultant increase in the demand and enhanced fraudulent practices were observed (Adamson 2004).

During the middle ages, tradesmen with specific speciality were given responsibilities to control and supervise the quality of products. For instance, specific troops were deployed in 1419 to prohibit the blending of wines collected from various geographical regions. Different countries opt different ways for controlling the food quality in one form or the other, just in order to assure the safety to the consumers. Later in eighteenth century, concept of chemistry came into focus, where the chemistry was used as analytical tool against the adulteration practices. Robert Boyle proposed the use of specific gravity's principle to detect the adulteration in various foods (Adamson 2004).

In the mid of the nineteenth century, periodic standardization was done in an organized manner for various analytical techniques. This was the time when the industries were not limited to specific regions but started spreading themselves to far off places. This was basically the period of 'Industrial revolution' when the industries started expanding themselves in various fields without following proper hygiene and sanitization. The society changes from rural to urban, domestic factories got converted to food factory system thereby placing strains on production and distribution of food. Adhering to such changes within such a short span, poverty came into existence leading to the development of various health issues among the population. Unfortunately, the awareness regarding the adulteration, hygiene, and quality was limited and was not taken into that much consideration. In 1858, municipal services were set up in Amsterdam to control beverages and foodstuffs. This was later followed by England in 1860 and with this the first modern food law was introduced in the world, i.e. 'An act to prevent Adulteration of Foods and Drinks'. The scientific approaches were made with this act to tackle the problems related to food and analyst was appointed to check the purity of drinks and foods (FAO 1999). Few years later, municipal services were established to control the drinking water. Various laws were then established in different countries like Belgium, Austria, Hungary, Italy, etc. Various institutions were established working on food quality and inspection. The efficacy of such institution can be measured by the reports of food and drug inspection, which records for controlling 176,000 samples, of which 11,000 were adulterated. The major activities based on quality and safety was observed in industrialized nations and countries like Canada, the USA, and Australia enacted these laws.

During the twentieth century, there occurred substantive development in India. Various laws related to adulteration of food and quality control were amended to ensure consistency in the quality of food articles sold in country from 1919 to 1941. Prevention of Food Adulteration Act was enacted in India and was then amended later on, which is still applicable. Other nations such as Portugal and Spain also amended their laws with significant differences and efforts are still being made after a number of amendments to harmonize these laws with proper functionality. It is quite obvious that there is still need of adjustments in various regulations as conditions at present varies from the past, when these regulations were made. Also, soon after the industrial revolution, there felt the need of developing such mechanisms that detect frauds and maintain financial accountability, the consequence of which, investors started depending on the financial organizations associated with the joint stock market. The concept of auditing was made mandatory after the crash of stock market in 1929. Along with establishments of modern standards, BRC, i.e. British Retail Consortium Global Standards were introduced which aimed to protect the consumer's health. It offers consistency, upgrades the supplier's standard, and helps in preventing the product from failure, thereby reducing the units of audits to be performed in manufacturing units.

12.3 Importance of Quality and Safety in Food Industry

Quality is considered to be the most important parameter in any product's market success. Earlier, the quality of food defines the lack of defects in it. Food safety is another important parameter in food industry that comes after assurance of food quality. It is the first ever demand and expectation of the consumer that the food he eats should be of good quality and must be safe. It is considered as integral part of food security. FAO defines food security as a situation where all people have constant physical, economic, and social access to food, which accomplish the nutritional requirement of an individual (World Health Organization 2020). For end users, i.e. customers, food safety is considered as the valuable parameter of food quality. Customers from the industrialized countries demand the product with consistent and high quality throughout the time. Various strategies have been opted by various governing bodies and food industries to ensure food safety due to increased risk of contamination. Examples of such contamination include unauthorized or illegalized food ingredients in various food supplements, melamine in different milk products, mercury-tainted milk powder, carbendazim's presence in juices, especially that of orange juice, etc. The food is considered unsafe mainly due to the three hazards, viz.

Fig. 12.3 Relation between QC, QA, and QM

(a) Physical hazard—includes extraneous matter such as insect matter, wood, metal, and glass.
(b) Chemical hazard—includes the presence of toxic chemicals such as herbicides, pesticides, and insecticides.
(c) Biological hazard—includes the presence of harmful microbes such as Salmonella and Listeria.

However, it is solely the responsibility and duty of manufacturer to eliminate the foreign particles from the produce he produces, which can be done by practising strict good manufacturing practices. The ultimate aim of following all these protocols is to ensure the safe delivery of products from farm to fork. The relation between quality control, quality management, and quality assurance is given in Fig. 12.3.

The major objective of HACCP is to prevent the human from the risks associated with food and to prevent the adulteration of food by various control measures in various steps of production as various health hazards are usually related with each step. It is applicable to every single step in production process, beginning from the cultivation of animal or plant (i.e. primary production process) including processing, manufacturing by the industry till its consumption by the customer. Various programmes like good manufacturing practices and other prerequisite SOPs (Standard Operating Procedures) should be established and followed before the implementation of HACCP (de Oliveira et al. 2016). Beside this, various other factors are also responsible for variability in the quality of finished products, for instance, defects in equipment, technologies, or methods used in process. Proper use of statistical process is a must to ensure and assure the good quality of the product.

The loopholes in food quality and safety, if not handled and managed properly may lead to social, economic and environmental consequences. As per the reports of WHO 2002, waterborne and foodborne diseases have consumed around 2.2 million lives, out of which 1.9 million were children. Outbreak of these diseases causes damage to trade, tourism which ultimately leads to unemployment and loss of earning among the population, resulting in social disturbance in the society. The prevalence of these diseases in countries highlights the major food safety concerns (WHO 2007). Besides targeting the people's health, these foodborne diseases also pose some economic consequences. They directly or indirectly impose burden on hospitals and other healthcare systems. According to a study in the USA, around 6.5–35 billion US dollars were spent in year 1995 to tackle 3.3–12 million cases suffering from foodborne diseases. Annual cost expenditure on healthcare system in European Union is about 3 billion euros, which persists solely due to *Salmonella* infections. Also, it is well understood that due to increased international food trade, the distance of the farm, from where the food was produced to the end user, i.e. customer has no longer been same. Thus, utilization of resources, energy, and exhaustion of gases (GHS) during the processes including consumption, transportation, and other factors is unavoidable. Therefore, the concept of food miles (distance from farm to end user), food chain should be sustainable so as to reduce the indirect burden on the environment. Food spoilage is another issue which arises due to poor quality and safety of food. Usually, every food product has limited shelf life and is perishable. High-quality food needs rapid minimal temperature conditions during the processing, the temperature abuse of which may lead to microbial growth, thereby causing spoilage of the food and onset of foodborne illness. According to International Institute of Refrigeration, around 300 MT of the produce is wasted annually because of improper refrigeration. Such big wastage of food along with resources is a big environmental persisting issue. Thus, considering the proper importance of food quality and safety in mind and by following the strict hygienic practices, these social, economic, and environmental loses can be overcome.

12.4 Steps in Food Analysis

Food analysis is said to be completed after completion of a number of steps, viz. sample preparation, performing analytical procedures, statistical data analysis, and reporting. The first step in food analysis starts from sample collection followed by sample preparation, which is further followed by performing of various analytical procedures. The selection of the sample should be done in such a way that it must represent the whole population. 'Population' refers to whole material, the properties of which have to be analysed, while 'sample' refers to some fraction of the selected population. The sample may be either one or more selected from the variable region of same population. The amount of sample is usually increased by keeping in mind the size of population. Further 'laboratory sample' is the one which is subpart of the sample obtained from the population due to its larger size. This fraction is actually used for the laboratory analysis. The analyst should perform this task with very precise and accurate measurements in order to obtain the accurate results. Also, this fact cannot be denied that the samples provide only the estimate of true value of whole population.

12.4.1 Sample Preparation

Before getting the sample ready for analysis, there are many other terms that need to be focused on. These includes sample size, sample location, and sample collection. Sample size is mainly dependent upon the expected disparity in properties of a population so that the sample may be able to represent whole of the population. Subsamples are taken in cases where the population size is too large and is performed till the ratio of good and bad sample lies under the predefined value, on the basis of which the population can be rejected or accepted. In case of homogenous population, sample location doesn't interfere with the result as all the subsamples possess similar properties. However, in case of heterogeneous populations, the location of collection of subsamples extremely matters. In such cases where there is heterogeneous population of large size, random sampling is preferred as there are less chances of human bias in it. Other parameters of sample location includes systematic sampling, in which the samples are taken from systematic time or location, say every eighth box from the batch to be analysed or sample to be collected from conveyor belt after every single minute; judgement sampling, in which subsamples are taken from the population by experience and judgement of the analyst. The collection of sample can be done either manually or by sampling devices. Picking the samples from conveyor belt or taking out samples from the sack using special containers or cups is a commonly practised example of manual sampling (Lazzaro and Pike 2014).

12.4.1.1 Homogenizing the Sample

Once the sample is collected by above-mentioned means, making the sample homogeneous is the very next step. The samples collected from the population are usually heterogeneous in majority of the cases and therefore, there is higher probability of variation in properties of samples collected from different location from same population. It is therefore compulsory to have the samples in homogeneous before they are analysed. Homogenization can be performed by the use of various mechanical devices depending upon the type of food (liquid, semi-solid, or solid). Usually mixers, slicers, blenders, and grinders are employed as mechanical devices for homogenization purposes. Other methods for homogenization include chemical methods where strong acids, base, and detergents are used; enzymatic method involves the use of enzymes like lipases, proteases, cellulases, etc.

12.4.1.2 Reducing the Sample Size

The homogenized sample is used to draw the manageable portion which is known as laboratory sample. This laboratory sample represents the properties of population and is used for further analysis.

12.4.1.3 Preservation of Sample

After the collection of sample, it is necessary to preserve the sample so as to maintain itself in its original form. Delaying in preservation of sample may lead to significant changes in sample, which may be physical, chemical, microbial, or enzymatic.

- Physical changes include loss or gain of moisture due to evaporation or condensation, disturbance in structural properties. The extent of physical changes can be reduced by means of adjusting the temperature where the sample is kept and by controlling the forces it experiences.
- Every sample contains loads of microorganisms in them, which exceeds above the safe levels, if not kept properly, leading to spoilage of the sample. Various treatments such as heat treatments, drying, freezing, and chemical preservatives can be used alone or in combination to limit the extent of microorganisms growing in food.
- Many food samples contain enzymes that may lead to various changes in properties of food before analysis is performed. Such enzymes include lipases, cellulases, and proteases. This ultimately ends up by providing erroneous data. Therefore, these enzymes must either be eliminated or inactive soon after the collection of samples, which can be done by the use of chemical preservative, heat treatment, freezing, drying, or combination of these, depending upon the type of sample.
- Samples rich in fat content may be prone to lipid peroxidation. Various factors such as elevated temperature, light exposure, pro-oxidants, and oxygen increase the rate of these reactions leading to spoilage of the sample at much faster rate. Such samples with higher content of unsaturated lipid can be stored under inert gas packaging such as nitrogen in dark rooms at refrigerated temperatures (Nielsen 1998).

12.4.1.4 Labelling the Sample and Its Identification

Samples should be labelled carefully from the very first day it is obtained so that if the problem persists during later stages, its origin can be identified. Following information is to be labelled before keeping the sample to storage:

(a) Description of sample
(b) Time when the sample was collected
(c) Location of sample
(d) Name of the person responsible for sample collection
(e) Selection method of sample
(f) Unique coding of sample

The analyst performing the tests should maintain a notebook in which detailed documentation of sample selection, its preparation procedures, and other results are to be recorded. As stated above, the samples must be labelled with unique code, the details of which should be properly recorded in the notebook by the analyst, so that in case if problem arises in future, the sample can be easily identified.

12.4.2 Analytical Procedures

Various analytical methods such as mass spectroscopy, liquid chromatography, gas chromatography, infrared spectroscopy, polymerase chain reaction, and many other analytical methods are widely used to assess the quality of food products (Tang et al. 2019). The detailed description regarding various analytical techniques and their selection for analysis of food is discussed later in this chapter.

12.4.3 Data Analysis and Reporting

Number of measurements is done on same sample to obtain the best value of data which indicates the value's reliability. Various techniques are used which enable us to gather the information of the laboratory sample, such as measure of central tendency, measure of spread data, sources and propagation of errors, rounding of significant figures, standard curves, and regression analysis. Measure of central tendency is the most commonly practised parameter. It gives the mean value that represents the overall properties for the number of measurements. Though it is not sure that which value is nearest to the true value, therefore we measure the mean using all the values and represent the result in the form of mean. Mean of the data is considered as the best estimated experimental value derived from measurements. Mean is calculated using the equation:

$$\overline{x} = \frac{x_1 + x_2 + x_3 + \ldots\ldots\ldots\ldots + x_n}{n} = \frac{\sum x_i}{n}$$

where $\overline{x}$ = mean, $x_1 + x_2 + x_3 + \ldots\ldots\ldots\ldots + x_n$ = individually measured values, n = number of measurements.

Median is another method that is used for determination which depicts the mid value of numbers within the group. Usually few values of the experiment lies above the mid value while other lies below it. Median is not commonly used as mean is considered as superior estimator.

The measure of spread of data depicts the closeness of the repeated measurements. Standard deviation is used as measure of spread in experimental measurements. Following equation is used to determine the standard deviation during experimental measurement:

$$\text{S.D.} = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \overline{x})^2}{n - 1}}$$

where SD is standard deviation, $\sum$ is to sum, X_i is each score in distribution, $\bar{x}$ is sample mean, n is number of cases in sample.

Sources of errors—Accuracy as well as precision are considered to be very important in all analytical determinations. Also, it is impossible to expect that analytical technique will be entirely error free. The best we can expect during analytical measurements is less variation and consistent data. Errors can be classified as determinate or systematic error, indeterminate or random error, blunder or gross error. Systematic error produces result which deviates consistently from expected value in one or the other direction. It is not only difficult but also time consuming to identify the source of such errors as it may happens due to inaccurate instruments or devices. For instance, an impaired pipette consistently delivering the incorrect amount of reagent and gives the result with high precision but would be ultimately inaccurate. Sometimes the quality of chemicals is the issue creator, poor quality, or impure chemicals give improper results. Such systematic errors can be overcome by timely calibration of the instruments, running blank samples, etc. indeterminate errors or the so-called random errors always there in an analytical measurement. As the name suggests, these errors fluctuate randomly and are unavoidable. For instance, detection of end point during titration, using of pipette, reading analytical balance, all these causes random errors. Although it is difficult to avoid such errors, but fortunately these are usually small. Gross errors produce the results with values that are too far from the true value. Using wrong reagent, incorrect techniques cause such errors. These blunders or gross errors can be identified and corrected easily (Garfield 1991).

Rejecting data—Sometimes it is observed that while performing an analytical experiment, one of the observation is deviated too much from the mid value and other value which might be due to blunder in the protocol. In such cases, that particular value can be rejected and is considered to be incorrect. For such type of cases, *Q-test* is usually performed in order to decide either to accept or reject that particular value.

$$Q = \frac{X_{BAD} - X_{NEXT}}{X_{HIGH} - X_{LOW}}$$

where X_{BAD} is questionable value, X_{NEXT} is next closet value to X_{BAD}, X_{HIGH} is the highest value of data set, X_{LOW} is the lowest value of data set.

It is to be noted that sample can be rejected if *Q-value* is greater than given value in Q-test table for number of samples that are to be analysed (Nielsen 1998).

12.5 Selection of Analytical Methods for Food Analysis

Food analysis or the analysis of food is an interdisciplinary approach as it includes the impact of various spheres including health, economic impact as well as societal impact. The chief objective of analysing any food material is to ensure that the food which is supposed to be consumed by the consumer is appropriate and acceptable in terms of its chemical constituents, quality aspect, organoleptic properties, safety, and also the nutritional value. There are major factors which can play in significant role in affecting the molecular and chemical composition of food products such as geographical distribution, genetic origin, environmental conditions, farming practices, breeding, soil fertility, water quality, processing conditions, presence of adulterants as well as any type of contaminant can affect the food material. Therefore, the proper analysis of food products is very essential as it can pose a significant effect on the health of consumers. Till date, it has not become possible to establish a single perfect method for analysing each and every component of food so the different analytical methods are used in association with each other to come to a final conclusion. Taking this into consideration, researchers and scientists are trying to develop a reliable, powerful, and relatively inexpensive analytical tool in order to analyse the quality and quantity of food products rapidly and at the same time, the results should be accurate too. Mass spectroscopy (MS), liquid chromatography (LC), gas chromatography (GC), infrared spectroscopy (IR), capillary electrophoresis (CE), enzyme-linked immunosorbent assay (ELISA), polymerase chain reaction (PCR), and nuclear magnetic resonance spectroscopy (NMR) are some of the most widely and extensively used analytical methods to assess and analyse the quality of food products (Tang et al. 2019).

Selection of a particular type of analytical food for carrying out food analysis largely depends upon certain inherent characteristics such as specificity, selectivity, precision, and accuracy. The food analyst must address any kind of interferences among the different properties of food, ensure high degree of specificity, variability of test results, percent recovery of the sample to be measured, and must compare the method being employed with the standard or traditional method of food analysis in terms of accuracy. Moreover, there are some other factors also which affect the selection of a specific type of analytical method to be used such as sample size, reagents, equipment, cost of method, usefulness in terms of time requirement, reliability as well as the need of method. The food analyst must ensure that the sample size must fit his needs as it should neither be too small not too large. At the same time, the sample should fit the equipment or glassware intended to be used for the procedure. The stability of equipment and reagent is equally important while selecting a suitable analytical method as it must be addressed whether the equipment being used is able to withstand temperature and pressure conditions or not. Cost of the analytical method to be employed must be taken into consideration as it should be apt in terms of reagents, equipment as well as personnel. Thus, these points are quite advantageous in order to evaluate the suitability of any particular analytical method being considered (Nielsen 2017).

Objective of the assay or measurement plays a major part in the selection of appropriate analytical method. For instance, in case of a rapid processing measurement, a less reliable and less precise method can be employed rather than using an official or stand test method. On the other hand, the official, reference, definitive, or primary methods are employed in settings or analytical laboratories which are very well equipped and have trained personnel. It is a common practice among the food industries and companies that they use the rapid and unofficial analytical methods as they are less time consuming and then validate their results against the standard or official analytical test procedures. For example, the moisture content can be determined using a calibrated moisture balance rather than hot air oven method which is more time consuming (Wetzel and Charalambous 1998).

Another major factor affecting the selection of analytical method include the characteristics of food constituents as the chemical components of food matrix such as carbohydrate, protein, and lipids affect the performance of several analytical methods. For instance, it has been reported in research studies that different types of disturbances are observed in the high-sugar and high-fat food products as compared to the low-sugar or low-fat food materials. Therefore, it is possible that the use of multiple analytical techniques may be required rather than a single technique for a specific food component owing to the complexity of food materials. The nature of food matrix or food system determines the digestion trials as well the extraction steps required for the accurate and precise analytical test results. A schematic layout of the food matrix (triangle scheme) based on the chemical composition of food products (carbohydrates, lipid, and protein) was suggested by AOAC International (Association of Official Analytical Chemists) in which foods were categorized into different levels and were rated as ‘high’, ‘low,’ or ‘medium’. These key nutrients, viz. carbohydrates, fats, and proteins are known to have a significant effect on the performance of any specific analytical method. By doing so, nine different combinations of high, medium, and low levels of carbohydrates, fat, and proteins were created which helps in determining the suitability of an analytical method based upon the composition of food matrix (Ikins et al. 1993; Lovett 1997; Ellis et al. 1997; Devries and Silvera 2001; Sharpless et al. 2004; Nielsen 2017).

Specificity, accuracy, sensitivity, and precision are the important characteristics while selection of any analytical method. At the same time, the variability of the data obtained from analytical method must be addressed considerably in order to detect and accept the differences related to a specific characteristic to the consumer. Sampling must be carefully done so to ensure that the number of selected samples to be analysed is a representative of the whole population. The equipment used for analysis must be appropriately standardized in order to obtain valid, accurate, comparable, and reproducible test results. Moreover, any limitations or drawbacks related to the performance of equipment must be addressed properly (Latimer Jr 1997; Nielsen 2017).

Method validity can also be determined by analysing the control materials or samples (check samples) against the samples to be tested which is an important part of quality control. These check samples services are provided by numerous government and non-government organizations (NIST, IRMM, BCR, AACC, etc.) in order to evaluate the dependability and reliability of any analytical method. The results so obtained after the analysis are then evaluated statistically followed by its comparison with other laboratory results to assess the degree of precision and accuracy. For instance, control samples of cereals-based samples are available for the analysis of ash content, moisture, protein, sugars, minerals, vitamins, total fibre (soluble and insoluble), etc. Similarly, another organization, viz. AOCS (American Oil Chemists’ Society) offer check samples for oilseeds, marine oils, toxins (aflatoxin), minerals, specialty oils, and trace minerals for determining the suitability of fatty acid composition as well as for nutritional labelling. The data so obtained is then analysed by the trained researchers from different countries to determine the degree of accuracy of work done by the personnel (Ambrus 2008; Nielsen 2017).

It is not necessary to obtain the standard reference materials from outside organizations only, instead the check samples can be prepared internally in the laboratory as well because standard reference materials or the check samples are an important tool to ensure the reliability and accuracy of any data obtained using analytical methods. For doing so, the control sample of appropriate type must be selected, gathered, mixed, and prepared so as to ensure uniformity. Moreover, the packaging and storage must be done carefully and a routine analysis of the control samples must be done along with the test samples. It is important that the sample which is intended to be used as a reference or control must be similar to the food matrix of test sample being considered for analysis (Nielsen 2017).

12.6 Brief Overview of Various Analytical Techniques

Currently, a large number of analytical techniques or methods are being used for the analysis of food products for quality control. The various methods widely employed in food processing industries and laboratories include techniques of sample preparation, biological, separation, spectroscopic, rheological, thermal, radiochemical, electrochemical, and enzymatic analysis. Sample preparation technique involves headspace, microwave-assisted extraction, supercritical fluid extraction, solid-phase extraction, purge and trap, pressurized liquid extraction, flow injection analysis, and microextraction. PCR, biosensors, recombinant DNA technology, microbiological analysis, immunological assay, and others can be used as biological techniques. Similarly, for the separation of different food components from a food matrix or system, techniques like LC, GC, SDS/PAGE, supercritical fluid chromatography, capillary electrophoresis, and LC-GC can be used. Techniques including mass spectrometry, NMR, fluorescence, infrared, X-ray, ultraviolet, atomic spectroscopy, light scattering, electron spectroscopy, and circular dichroism can be employed for the qualitative and quantitative analysis of food materials. Creep, oscillatory shear, rheometry, viscometry, stress relaxation, normal stress, etc. can be used to determine the rheological properties of food products. Differential thermal analysis, DSC, thermogravimetry, and thermochemical techniques are used for the thermal analysis. Radiochemical and electrochemical techniques involve radioimmunoassay, isotropic method, radiochemical, radiometric, radioisotope, radiotracer, radiolabelling, biosensors, voltammetry, potentiometry, amperometry, polarography, conductometry, and coulometry. AACC International has also listed the procedures for the quantitative analysis of food materials including ash content, moisture, acidity, amino acid composition, crude fat, fibre, nitrogen, reducing sugar, total sugar, vitamin, mineral, and physicochemical tests (Cifuentes 2012). A brief overview of the various techniques is represented in Table 12.1.

Table 12.1 An overview of various qualitative and quantitative analytical techniques

Sr. no	Analytical technique	Application	Reference
A	**Sample preparation techniques**		
1.	Subsampling	• The most important and potential source of error in analysing any food material is the sample selection. • The test sample withdrawn from the whole lot of sample is the representable sample. • The sample must be drawn based upon the relationship of test sample with the whole lot of food.	Nielsen (1998), Cifuentes (2012), Moldoveanu and David (2021)
2.	Compositing	• The admixture of either two or more than two portions of any food material after subsampling is known as compositing. • The average of normal variation between the two different samples is done as a result of compositing. • It is essential that the individual samples selected by using subsampling technique should have same size, volume, and weight so as to make the sample homogenous and uniform in nature.	Nielsen (1998)
3.	Chopping, grinding, mixing	• The type of equipment used for the physical and mechanical processing of food products depends largely upon the food product to be treated as well as the moisture content of food. • The various equipment involved in this technique include mechanical choppers, grinders, mixers, mill, and blenders. • The food analyst must ensure that the mechanical process should prevent any changes in the food product as it can result in inaccurate and biased analytical results.	Nielsen (1998)
4.	Freezing and thawing	• Freezing is done to prevent any change in a food prior to analysis or to reserve storage. • The composition of the food should not be changed while	Nielsen (1998)

(continued)

Table 12.1 (continued)

Sr. no	Analytical technique	Application	Reference
		thawing; therefore, it should be done gradually, without giving heat and in a closed container so as to reserve the moisture content of food.	
5.	Microwave-assisted extraction (MAE)	• This method involves the extraction of compounds by using microwaves and can result in getting a higher yield in short span of time. • This technique is based on the mechanism in which the energy absorption takes place as soon as the microwave is passed through the solvent and gets converted into thermal energy. • Dipole rotation and ionic conduction accompany the heating caused by microwaves. • MAE is superior as it can be employed at the same temperature by the use of less solvent as compared to the conventional extraction techniques. • This technique can be used to extract various phenolic and biological compounds such as essential oils, organic acids, and fatty acids.	Proestos and Komaitis (2008), Sonar and Rathod (2020)
6.	Solid-phase extraction (SPE)	• SPE technique is a method of sample preparation in which a fused silica fibre is coated with a suitable stationary phase as a result of which the analyte present in the sample gets extracted and concentrated onto the fibre coating. • This technique is cost-effective in terms of solvent and disposal cost as well as saves time. • This method is generally used in combination with other techniques like gas chromatography and mass spectroscopy and is used to extract organic compounds (volatile as well as non-volatile)	Kataoka et al. (2000), Hanhauser et al. (2020)

(continued)

Table 12.1 (continued)

Sr. no	Analytical technique	Application	Reference
		from the biological, environmental, and food samples. • It is applied for the analysis of different aromatic and flavouring compounds present in the food samples. • This technique can also be employed in order to monitor the water quality for the identification of heavy metals and other contaminants in water samples.	
7.	Supercritical fluid extraction (SFE)	• SFE technique involves the use of supercritical CO_2 for the selective separation of desirable compounds without causing any degradation or toxicity of the food product. • It is used as an effective technology for the quantitative as well as qualitative analysis of the constituents which are naturally occurring and heat-labile in nature. • This technique can be used for the separation of high-quality essential oils (such as lemon oil, rosemary oil, lavender oil) and its derivatives, extraction of edible fats and oils, antioxidants, pesticides as well as for the detoxification of shellfish. • It is a promising technique for the extraction of microalgal compounds and thermolabile molecules and at the same time reduces energy costs by preserving the natural properties as well as qualities of compounds considered to be bioactive in nature.	Mohamed and Mansoori (2002), Molino et al. (2020)
8.	Flow injection analysis (FIA)	• FIA technique is widely used by researchers in order to analyse the sulphite content present in foods and beverages. • It is a cheap, accurate, simple, and quick analytical method by using relatively less amount of	Claudia and Francisco (2008), Bezerra et al. (2020)

(continued)

Table 12.1 (continued)

Sr. no	Analytical technique	Application	Reference
		reagent, small sample volume, less toxicity, and simple instrumentation. • It has been suggested through research studies that the implementation of FIA is accompanied by an increase in the throughput of analyte, decreased losses, minimized generation of waste as well as less chances of contamination. • The procedure involves two phases, viz. the former being extraction of sulphating agent and latter involves the injection of extracted sulphating agent into the liquid extract and its detection in the FIA system.	
9.	Pressurized liquid extraction (PLE)	• This technique is also known as accelerated solvent extraction (ASE), pressurized hot solvent extraction (PHSE), pressurized fluid extraction (PFE), high pressure solvent extraction (HPSE), subcritical solvent extraction (SSE) and high pressure, high temperature solvent extraction (HPHTSE). • PLE involves the extraction of compounds using solvents at high temperature and pressure. • This technique is considered to be a green and sustainable technique for extracting bioactive compounds from its natural as well as synthetic sources. It is also used in the detection of various bioactive compounds present in different food samples. • Various contaminants including polycyclic aromatic hydrocarbons, polychlorinated compounds, alkylphenols, pesticides, metals, drug residues, natural toxins, and other matrix components like polyphenols, essential oils, fat matter, pharmacologically active	Carabias-Martínez et al. (2005), Alvarez-Rivera et al. (2020)

(continued)

Table 12.1 (continued)

Sr. no	Analytical technique	Application	Reference
		compounds can be extracted by using PLE technique as an analytical method in food analysis.	
B	**General analysis techniques**		
1.	Heating and drying	• Various heating devices used in laboratory include hot plates, mantles, steam baths, water baths, burners, convection oven, vacuum oven, desiccator, etc. • In order to ensure uniform heating of sample, ovens are most extensively used. • Steam bath followed by oven heating must be used for extremely wet food materials as steam bath treatment allows evaporation of moisture prior to drying.	Nielsen (1998), Cifuentes (2012)
2.	Ashing and digestion	• The removal of organic matter to obtain inorganic residue by employing heat treatment using muffle furnace is known as ashing. • It is used to determine the total inorganic residues as well as for the analysis of trace minerals present in the sample. • The major drawback associated with dry ashing is that it is generally difficult to extract the metal completely from the ignited residues. • Another method involving the destruction of organic matter to estimate the inorganic residues is by acid digestion in which acids like H_2SO_4 and HNO_3 are used either individually or in conjunction. • Acid digestion technique used for the analysis of metal residue is accompanied with high chances for the sample to become contaminated. • Grossbier and Schoenfuss (2021) conducted a research study to do the comparative analysis between conventional	Nielsen (1998), Grossbier and Schoenfuss (2021)

(continued)

Table 12.1 (continued)

Sr. no	Analytical technique	Application	Reference
		digestion and microwave-accelerated digestion (MAD) method for the determination of equivalency. It was concluded that the rate of MAD was much faster than the conventional one for the sake of mineral analysis.	
3.	Extraction	• Extraction involves the partitioning of material between two phases. • Liquid–liquid extraction is based upon the extractant solubility in the two liquids. On the other hand, liquid–solid extraction is bit complicated due to the physical occlusion of extractant inside the solid material (inert in nature). • Extraction of fat content from a meat sample is one example of extraction technique where Soxhlet unit is utilized. The finely divided solid sample is mixed with extractant (solvent) which provides a good siphoning action. • Multiple extractions are often necessary for the quantitative analysis of food sample as a single extraction may not be suitable for partitioning of a substance.	Nielsen (1998)
4.	Distillation	• Distillation (simple, steam, and fractionation) is an analytical method used for the purification of a substance. • Simple distillation involves a liquid solution which is heated to a temperature when vapours begin to form followed by condensation of vapours and its collection. • A steam distillation unit consists of steam generator, sample flask and a condenser. Fractional distillation involves the process of separating a liquid mixture consisting of two or more constituents with close boiling points.	Nielsen (1998)

(continued)

Table 12.1 (continued)

Sr. no	Analytical technique	Application	Reference
		• It allows the separation of components on the basis of their volatility.	
5.	Titration	• Titration is one of the most extensively used analytical techniques for the analysis of check samples in laboratories. • It allows the quantitative determination of the concentration of an unknown or known analyte by using a titrant or titrator which is a standard solution of known volume and concentration.	Nielsen (1998), Rohindra and Lata (2020)
C	**Determinative and separation techniques**		
1.	Paper chromatography	• Paper chromatography is an important method used in food analysis for the extraction, identification, and isolation of synthetic food colours from various food products such as soft drinks, candies, and jellies. • It is based upon the principle of partition of compounds in which they get distributed between stationary phase (paper fibres) and mobile phase (developing solvent). • The components are identified and separated on the basis of Rf value of standard solution and samples.	Bachalla (2016)
2.	Gas-liquid chromatography	• This analytical technique is extensively used for the qualitative and quantitative analysis of food constituents, additives, flavouring compounds, aromatic components, contaminants, pesticides, preservatives, pollutants, natural toxins, transformation products, drugs, packaging materials, etc. • Gas chromatography helps to analyse the semi-polar, non-polar, volatile, semi-volatile chemicals, sterols, oils, fatty acid chains, off-flavours, etc. present in the food materials.	Lehotay and Hajšlová (2002), Cortes (2020)

(continued)

Table 12.1 (continued)

Sr. no	Analytical technique	Application	Reference
		• The time consumed in the analysis can be shortened by increasing the flow of carrier gas, increasing column diameter, heating the column, shortening the column length, or by reducing the viscosity of carrier gas. It ensures the required selectivity.	
3.	High performance liquid chromatography (HPLC)	• HPLC is employed for the separation of a mixture of compounds for the identification, quantification followed by purification of individual constituents of the mixture. • It plays an important role in food industries for quality role as it is used to analyse and separate food additives, preservatives, toxins, contaminants, and other food components. • It is based on the principle of column chromatography in which a high pressure of the mobile phase is applied to pump it through a packed column.	Nollet and Toldra (2019), Akash and Rehman (2020)
4.	Spectrophotometry	• Spectrophotometry is based upon the principle of reflectance of light by the sample material when it is exposed to a source of polychromatic light. • It helps in the detection of impurities, quantitative estimation of concentration of a component, characterization of proteins, structure elucidation of organic compounds, detection of functional groups in food constituents, determination of food dyes, quality evaluation of agricultural commodities, and many more.	Polesello et al. (1983)
5.	Refractometry	• Refractometry technique is used to determine the nature of food products. It is a method for the qualitative analysis of an unknown compound based upon the refractive index of the compound being considered, and	Bradley (2010)

(continued)

Table 12.1 (continued)

Sr. no	Analytical technique	Application	Reference
		it varies with the concentration of compound, wavelength of light as well as temperature. • It is used to determine the moisture of condensed milk, liquid sugar products, total soluble solids of fruits and fruit products.	
6.	Microscopy	• Electron microscopy works on the principle at which imaging is performed at room temperature and under high-vacuum since gas molecules may scatter electrons that reduce image resolution. • The wavelength range of visible light should be from 400–800 nm which adheres to the resolution of optical microscopy techniques. • High resolution imaging can be achieved using electron microscopy especially in food powders.	Burgain et al. (2017)
7.	Capillary electrophoresis (CE)	• CE is a technique used for the determination of free amino acids using optical detection, which is mainly based on the derivatizing agent, 4-Chloro-7-nitrobenzo-2-oxa-1,3-diazole (NBD-Cl), which employs laser-induced fluorescence (LIF) detector. • Other derivatizing reagents such as 6-aminoquinolyl-N-hydroxysuccimidyl carbamate (AQC), 9-fluorenylmethyl chloroformate (FMOC-Cl), naphthalene dicarboxaldehyde (NDA), o-phthalaldehyde (OPA), phenylisothiocyanate (PITC), and dansyl chloride are used for this detection. • It is used for the analysis of food additives, herbicide, animal nutrition, and detergents.	Omar et al. (2017)
8.	Supercritical fluid chromatography	• SFC allows the use of higher flow rates with lower pressure falls through the column. It leads	Bernal et al. (2013)

(continued)

Table 12.1 (continued)

Sr. no	Analytical technique	Application	Reference
		to better efficiency in a short duration of time as well as reduced utilization of organic solvents, which is carried out in subcritical conditions. • CO_2 is the most frequently used supercritical fluid owing to its correlating properties such as non-toxic, non-explosive, considered generally recognized as safe (GRAS) reagent and easily achievable experimental conditions, such as temperature 31 °C and pressure 73 bar.	
9.	Mass spectroscopy (MS)	• MS is based upon the principle of generation of ions from organic and inorganic compounds followed by their separation and detection both quantitatively as well as qualitatively. • It is used for the analysis of pesticides, lipids, drugs, mycotoxins, caffeine, contaminants, volatile compounds, toxins, phthalates, metabolites, amino acids, plasticizers, etc.	Nollet and Munjanja (2019)
10.	Fluorescence	• Fluorescence spectroscopy technique is used for the monitoring of food standards and analyses the food quality. • It is a quick, easy, rapid, and non-destructive method of analysing the quality of foods including dairy products, meat and seafood, eggs, vegetable oils, honey, wines, beers as well as detecting the various contaminants present in food products. • It is known to be a consolidated technique for the quantification of dissolved organic matter in a fast matter.	Sádecká and Tóthová (2007), Carstea et al. (2020)
11.	Nuclear magnetic resonance (NMR) spectroscopy	• NMR spectroscopy is an analytical technique which works on the principle of magnetic properties of substances.	Hatzakis (2019)

(continued)

Table 12.1 (continued)

Sr. no	Analytical technique	Application	Reference
		• It is used for the structural characterization of apple allergens and analysis of organic acids, conjugated linolenic acid, amino acids, antioxidants, carbohydrates, sugars, pectins, coffee, flowers components, phytochemicals, tea, fish, honey, spices, etc.	
12.	Infrared spectroscopy	• It is based upon the principle of absorption of electromagnetic radiation between 780 and 2500 nm wavelength. • The physical properties and chemical composition of food components (carbohydrates, water, proteins, fat) can be determined using IR spectroscopic technique. • It finds its application in the analysis of cereals and cereal products, dairy products, meat, fish, fruits, vegetables, confectionery, beverages and to assess the authenticity of food products.	Osborne (2006)
13.	X-ray spectroscopy	• X-ray spectroscopy is a non-destructive analytical technique for mineral analysis in cement industry, geology, petroleum, chemical, medical, and food industries. • Estimation of minerals like chromium, lead, titanium, iron, and zinc can be done by using this non-invasive analytical method.	Sosa et al. (2018)
14.	Ultraviolet spectroscopy	• This technique is extensively used in food industries for quality control and helps to detect adulterants, contaminants, identify the origin of food materials, variety of wine, analysis of food matrices (milk, coffee, wine, oil, meat), and differentiation between decaffeinated and caffeinated coffee.	Power et al. (2019)

(continued)

Table 12.1 (continued)

Sr. no	Analytical technique	Application	Reference
15.	Circular dichroism (CD)	• It is a spectroscopic technique involving conformational study of proteins, nucleic acids, and biomolecules. • CD data involves the study of structural composition of proteins, unfolding of proteins as a result of temperature or addition of chemical denaturants, stability of proteins, and effect of mutations on the structure of protein molecules.	Martin and Schilstra (2008)
D	**Biological techniques**		
1.	Biosensors	• Biosensors are widely used in food industries which involves the interaction of a biological element with the sample under observation (test sample) as a result of which a biological response is obtained. It is further transcribed into electrical signals with the help of a transducer. • This technique is used for the detection of toxic compounds, organophosphates, ammonia, methane, pathogenic organisms, water-soluble vitamins, antibodies, and chemical compounds. • It is used to test the quality of water and to measure carbohydrates, proteins, alcohols, phenols, acids, gases, inorganic compounds, amides, and certain heterocyclic compounds. • It plays an important role in the quantitative detection of ultra-low concentration of biomarkers in a very sensitive, robust, reliable, and selective manner.	Scott (1998), Mello and Kubota (2002), Purohit et al. (2020), Chandra et al. (2012), Choudhary et al. (2016), Deka et al. (2018), Mahato et al. (2018)
2.	PCR (polymerase chain reaction)	• It is a precise method of amplification of a desired fragment of DNA from a mixture of molecules of DNA. • PCR is used to detect genetically modified organisms, food toxic components	Klančnik et al. (2012)

(continued)

Table 12.1 (continued)

Sr. no	Analytical technique	Application	Reference
		(pathogens and contaminants), identify various species of dairy and meat products. It helps in quality control and protects human health against harmful consequences of toxicological compounds and hence ensures microbiological safety.	
3.	Microbiological analysis	• Microbiological analysis of food products is based upon accuracy of test, recovery of target organism, limit of detection of method, comparability of results, microbial growth inhibition, and competitive growth. • It assists in the Hazard Analysis Risk in management of food safety, verifying HACCP plans as well as to assess the storage stability or shelf life of food products.	Stannard (1997)
4.	Immunological technique	• Immunosensors are employed for the detection of any toxic substance present in food products which can pose deleterious effects on human health. • Immunological technique is used to detect veterinary drugs, anabolic steroids, pathogenic bacteria, aflatoxins, mycotoxins, GMOs, and pesticides present in the food samples. • SPR immunosensor helps to analyse food materials to determine the presence of food-borne pathogens and toxic compounds in food commodities.	Ricci et al. (2007)
E	**Rheological techniques**		
1.	Oscillatory shear	• It is a common rheological technique used for the determination of viscoelastic properties performed on rheometers either stress-controlled or strain-controlled. • This testing can be divided into two types, viz. small	Melito et al. (2012)

(continued)

Table 12.1 (continued)

Sr. no	Analytical technique	Application	Reference
		(SAOS) and large amplitude oscillatory shear (LAOS), where the former testing is performed in the linear viscoelastic region (LVR) and latter beyond the region of linearity. • LAOS has been used to study the mechanical properties of dispersed systems, such as emulsions, suspensions, and foams.	
2.	Rheometry	• Rheometry describes the relationship between the stress acting on a given material and the resulting deformation and/or flow that takes place in a specific period of time. • Stress is the measurement of force per unit of surface area and is expressed in Pascals (Pa). while strain represents a dimensionless quantity of relative deformation of a material that took place. • It is widely used to analyse rheological properties of food gels such as gelatin, jellies, and cooked egg whites; baked products, in starch and dairy products.	Tabilo-Munizaga and Barbosa-Cánovas (2005)
3.	Viscometry	• Capillary viscometer works on the principle of the drop of the pressure along the capillary which is transformed into a shear stress at the wall and the volumetric flow rate to shear rate. • It is used to analyse the viscosity and textural properties of food such as in wheat dough, soups, butter, honey, and sauces.	Campanella et al. (2002)
4.	Stress relaxation	• Stress relaxations provide information on permanent cross-linking, effects of different chemicals and enzymatic additives on baking quality as well as distinguish products from different origins. • It is an objective method for	Bhattacharya (2010)

(continued)

Table 12.1 (continued)

Sr. no	Analytical technique	Application	Reference
		the quality assessment of bread, wheat, and pulse-based doughs. Practical applications include design of product formulation, dough handling systems, and for the purpose of sheeting/ flattening. • The desirable characteristic for flattening purpose is that dough needs to possess a low value of residual stress for the preparation of chips and flakes.	
F	**Radiochemical and electrochemical techniques**		
1.	Radioimmunoassay	• Radioimmunoassay evaluates the quality and wholesomeness of food which requires a sample containing the antigen of interest, a complementary antibody, and a radiolabelled version of the antigen. When the radiolabelled antigen is added, it competes with the sample antigen and displaces it from the antibody. • The solution containing antigen–antibody complex is denser, so centrifuging the mixture is essential which allows separation, resulting in a pellet containing the bound sample antigen/radiolabelled antigen.	Grange et al. (2014)
2.	Radiometric	• Radiometry is a temperature measurement technique which is based on the principle where microwave frequency range, the thermal noise power emitted by a dissipative body is directly proportional to its temperature. So, the temperature inside a dissipative material can be determined using a radiometric system. • Quality control has one of the main concerns which is temperature control which is measured by infrared, optic fibre, and thermocouples measurements.	Cresson et al. (2008)

(continued)

Table 12.1 (continued)

Sr. no	Analytical technique	Application	Reference
3.	Voltammetry	• Stripping voltammetry is the most sensitive electroanalytical technique. The analyte is accumulated on a working electrode by controlled potential electrolysis followed by the dissolution of the deposit when a linear ramp is applied to the electrode. It results in the production of a detectable current at the electrode surface. • Anodic stripping voltammetry (ASV) was the first technique to be developed. It was mainly applied to trace analysis of heavy metal ions using a hanging mercury drop electrode. • It is generally used for the determination of food contaminants (toxic metals, pesticide, fertilizers, and veterinary drugs residuals), trace essential elements, food additive dyes, etc.	Alghamdi (2010)
4.	Potentiometry	• The basic principle of potentiometry is voltage measurement at null current. When an electrode is placed in a solution, it tends to send its ions into the solution and those ions in the solution react with the electrode. • Its advantages include low cost, ease of commercial production, and the possibility of obtaining selective sensors. • They are used to monitor cheese fermentation, evaluation of the impact of micro-oxygenation and oak chip maceration on wine composition, monitor changes during beer brewing, etc.	Pomeranz and Meloan (1994), Sliwinska et al. (2014)
5.	Amperometry	• Amperometry is the electroanalytical technique that involves the application of a constant reducing or oxidizing potential to an indicator electrode as well as measurement	Adeloju (2005), Scampicchio et al. (2008)

(continued)

Table 12.1 (continued)

Sr. no	Analytical technique	Application	Reference
		of the resulting steady-state current. • Amperometric biosensors include electronic tongue, which works on the principle of an electrochemical conversion occurring at an electrode and the resulting current is measured. • Biosensors are used for the analysis of complex mixtures such as wine and must.	
6.	Conductometry	• Conductometric sensors work on the principle of changes in conductivity, which result from the interactions with the volatile odorants, leading to the changes in the sensor's electrical resistance. • The three types of conductometric sensors used most commonly in electronic noses include metal oxide semiconductors (MOS), conductive polymer (CP) sensors, and metal oxide semiconductor field-effect transistors (MOSFET). • Some of the food applications include the monitoring of spoilage (like red wine), the dehydration of tomatoes, determination of the meat freshness, classification of fruits based upon ripeness and detection of aflatoxins in corn.	Sliwinska et al. (2014)
G	**Some other techniques**		
1.	Microfluidics	• Microfluidics is a new and emerging technology that is utilized in 3D printing which offers various advantages in terms of less generation of waste, consumption of reagent, cost, and other factors. • Different methods including micromilling, micromachining, hot embossing, etc. are used to develop microfluidic devices. • This analytical technique is used for the chemical and	Nielsen et al. (2020)

(continued)

Table 12.1 (continued)

Sr. no	Analytical technique	Application	Reference
		biological analyses and is considered to be one of the most advanced, well developed, and emerging technology in the field of 3D printing. • There has been an emerging research to study the application of 3D printers for the development of microfluidic devices. But it was concluded that the creation of small interior fluidic features is quite difficult with the use of 3D printers. On the other hand, surface feature devices are beneficial for the development of microfluidic structures.	
2.	Smartphone-based food analysis	• Smartphone-based food analysis technique has gained much attention recently different sectors, viz. food industry, agriculture sector, healthcare, and environmental monitoring. • Owing to the numerous useful components of smartphones such as Bluetooth, Wi-Fi, battery, processor, cellular data, camera, video, and visual display; it allows the rapid, low-cost, and easy measurement as well as detection of components. • Unlike laboratory equipment and tests, the smartphone-based technology can't be used alone. • This technology can be used along with other methodologies like fluorescent imaging, microsphere fluorescent immunoassay, colorimetric assays, microfluidics, lateral flow immunoassay, colorimetric imaging, voltammetry assay for the detection of bacteria in water, antibodies in milk, allergens in food samples, aflatoxin in maize, fluoride, and catechols in water..	Rateni et al. (2017)

(continued)

Table 12.1 (continued)

Sr. no	Analytical technique	Application	Reference
3.	Paper-based diagnostics	• This technology is highly appreciated identification of the causative agent of any underlying disease in the healthcare sector and also for the detection of contaminants in food samples. • The utilization of paper-based biosensors has gained commercial attraction due to its suitability for the analysis of biofluids being portable in nature, specific, user-friendly, rapid, easily transportable, highly sensitive, affordable, and easily available. • Various types of paper-based biosensors used are dipstick type paper-based biosensor, paper-based lateral flow assay, μ-PAD, and smart accessories-based paper bio-analyser. • This technology is used for the detection of glucose, uric acid, protein, pH, lactate, etc.	Mahato et al. (2017)
4.	Bluetooth devices	• Automated dietary monitoring assessment is a nutritional approach which helps in the analysis of food in terms of nutrition, assists dietary recall and nutritional assessment. • Nowadays, Bluetooth devices are being used widely for monitoring an individual's dietary behaviour. The advanced automated dietary monitoring systems help in the estimation of calorie (energy) consumption based on the number of detected bites by an individual. • Gao et al. (2016) conducted a research study in order to study the sound pattern of different food samples for the detection of eating behaviour. Food samples were categorized into four groups, viz. very soft, soft, hard, and very hard.	Gao et al. (2016)

12.7 Conclusion

With compliance to food and trade laws, the analysis of food products is very important in order to avoid contamination of foodstuffs, study the chemical composition, food processing, and quality control. For the sake of achieving high standard in terms of food safety, various analytical techniques are compulsorily and indispensably employed in food industries. It has been concluded in many researches that food industries often face serious challenges with respect to adulteration and high capital cost of food control systems. Therefore, it is highly desired to develop rapid, effective, and sensitive analytical techniques for quality control and food analysis.

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