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A review on recent advanced spoilage detection techniques for fruits and vegetables

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Abstract
Spoilage of vegetables and fruits is an area of global concern, causing various health-related problems and resulting in higher economic losses for the fruits and vegetables production sector. Spoilage may rise from insect damage, enzyme activity and physical damage by microbial contamination. Although some techniques and detection methods for determining spoilage are currently available and the conventional approaches have significant restrictions and disadvantages, such as they are time-consuming, laborious and relatively high-cost. This review article concentrated on the recently developed techniques and the applications of various multi-sensor systems in the food sector. The main objective is to provide a problem-oriented look at the spoilage of fruits and vegetables, its detection and how to control it by different methods. Furthermore, these studies also explore various aspects of spoilage along with rapid spoilage detection techniques for fruits and vegetables. Some of the innovative recent techniques as biosensors, electronic noses, electronic tongues, smartphone-based technologies to avert the deterioration, early detection of spoilage and prolong the shelf life. These spoilage detection techniques offer great potential for microbial detection with the rapid development of science and technology and computer vision techniques to the development of the horticultural field.

Keywords: Fruits and vegetables, detection, spoilage, shelf-life, biosensors, electronic nose, electronic tongue

1. Introduction
Food safety is a global major concern that has recently achieved public attention owing to the accessibility of info about food products via the rise of social media, whereas food spoilage is also another major global health problem and one of the major concerns from the manufacturing to utilization. In developed countries, the fruits and vegetables consumption is around 15-20% of total amount and the utilization rate of fruits and vegetables is dramatically increased not only in India but in the whole world due to the awareness of people. India is the 4th largest supplier of fruits, as well as the 2nd largest producer of vegetables (Ali *et al.*, 2020) [37]. As per estimation, around 20 percent of fruits and vegetables are lost every year due to the microbial spoilage. According to estimation, around 1.3 billion tons of horticulture commodities are lost or squandered each year, accounting for 30 percent of global food output meant for human consumption (Mir *et al.*, 2018) [52].
Early detection of spoilage in fruits and vegetables is an essential step that can aid in the influence of a spoilage infection and the avoidance of heavy losses of fruits and vegetables (Rajapaksha *et al.*, 2019) [47]. Fruits and vegetables contain a wide range of biologically active and non-nutritive secondary metabolites defined as "phytochemicals" with disease-fighting qualities. A healthy diet must include fresh vegetables and fruits because of their high nutritive value including minerals such as magnesium and potassium, vitamins B, C, and K (Yahia *et al.*, 2019) [9].
Raw fruits and vegetables have the capacity to avoid chronic disorders; heart disease, cancer, diabetes and obesity, as well as many other micronutrient deficiencies, mainly in developing nations. Raw vegetables are being identified as crucial vehicles for the prevention of transmission pathogens (Ramees *et al.*, 2017) [53]. Because fresh vegetables are consumed fresh or moderately cooked to maintain their flavor or nutritive value, they can be a source of numerous food poisoning and outbreaks. Spoilage is a metabolic process that causes changes in the sensory characteristics of food to make it undesirable and unacceptable for human

consumption. Spoilage can also result from enzyme activity and microbial contamination in addition to physical damage and infestations. The spoilage microorganisms such as *Botrytis, Pseudomonas, Acinetobacter and Alicyclobacillus* are responsible for substantial economic losses to food producers by facilitating the spoilage of vegetables, fruits, and other foods (Pinu, 2016) [10].

Most fruits and vegetables have a short shelf life and are more vulnerable to spoilage. Food degradation is primarily caused by enzymes, while rancidity and oxidation are responsible for food degradation in other foods. Because they are thought up of living tissues, fruits and vegetables are perishable and extremely vulnerable to loss (Arroyo *et al.*, 2020) [44]. Microorganisms such as bacteria, molds and yeast are the most destructive spoilage agents. To ensure the safety of human consumption, microbiological quality should be tested. Traditional approaches for identifying microbial species in foods, such as biochemical and culturing techniques and also has the limitation of being labor-intensive and time-consuming are still used (Rotariu *et al.*, 2016) [27]. The invention and application of innovative instrumental techniques are required to detect rotting in fruits and vegetables as they are rapid, reliable and low-cost. There is a need for the implementation and advancement of novel instrumental methods as fast, dependable and low-cost devices for detecting spoilage in fruits and vegetables (Yousuf *et al.*, 2018) [42]. The research and development of such multi-sensor systems is now underway (Barth *et al.*, 2009) [28]. The main methods include biosensors, electronic nose, electronic tongue and smartphone-based technologies (Tahara and Toko, 2013) [60].

A thorough understanding on cause of spoilage, early spoilage detection methods in fruits and vegetables are required. However, only a few investigations have been performed in the past to investigate early spoilage detection methods and to further clarify the existing study's overview, various components which are discussed in this review.

2. Microbial spoilage of fruits and vegetables

Spoilage is defined as any change in fruits and vegetables that render them unsuitable for human consumption. Such a change will affect both safety and quality related, whereas microbiological quality changes affect colour, flavour, texture, and aroma. Microbial spoilage of food causes severe foodborne intoxications and increased economic damage in the food-producing area. Microbiological safety has become an essential issue for both consumers and the food manufacturing industry, and regulations requiring the implementation and evaluation of control systems have been created (Caya *et al.*, 2019) [41]. Many fruits and vegetables provide optimum conditions for various microorganisms to survive and grow. Internal tissues are nutrient-dense and, in the case of vegetables have a pH close to neutral. Polysaccharides, cellulose, hemicelluloses and pectin are the main components of their structures. Among storage polymers, starch is the most common. Spoilage microorganisms utilize extracellular lytic enzymes to deteriorate such polymers and other intracellular components of plants act as nutrient medium for their growth (Sahu and Bala, 2017) [35].

The outer layer of epidermis in fruits and vegetables is usually protected by a natural waxy layer comprising the polymer cutin. Higher temperatures, high humidity, and air throughout storage increase the chances of spoilage, which causes microbial growth (Thakur and Ragayan, 2013) [40]. The term "rot" refers to microbial deterioration of vegetables. The different types of rot can be identified by their appearances. Soft rot, black rot, stem-end rot, pink rot, and grey rot are the most prevalent rots, whereas microorganisms are found on the surfaces of fresh fruits but may usually limit their growth after harvest (Ceto *et al.*, 2016) [56]. Many microbial species multiply quickly and cause spoilage in minimally processed cut vegetables. The expansion of spoilage microorganisms may be slowed by collection or packaging (Randhawa *et al.*, 2018) [36].

The common indicators of physicochemical deterioration variations in procedures are frequently found in the flavor and color of fruits and vegetables or other food products are inter-related. The ultrasound technology, extreme heat and high hydrostatic pressure are the physical treatments which can cause biochemical reactions in food. Color changes, increased viscosity, gelation, or sedimentation may occur as a result of chemical processes such as lipolysis and lipid/enzyme oxidation. (Gul *et al.*, 2017) [19]. After-harvest biochemical and microbial variation have a significant effect on the quality along with shelf life of fruits and vegetables (Sankarankutty, 2014) [26]. Throughout the production and storage of food products, there exists a unique microbial flora. In addition to the microorganisms present in raw food, the conditions in which food is produced, preserved, or stored also affect the composition of a microbe's population (Membre and Dagnas, 2016) [21].

3. Scenario of microbial spoilage in India

The country ranks third in the world for its fruit and vegetable production after Brazil and China. It contributes 10% of global fruit production and 14% of global vegetable production. Based on the nature and composition of fruits and vegetables, these are highly vulnerable to spoilage as compared to cereals and this spoilage occurs after harvesting, handling, during transportation, storage period, marketing and processing. (Jayan *et al.*, 2019) [14]. As a result, early detection of spoilage provides numerous benefits for quality control in the fruit and vegetable industry.

4. Impact of microbial spoilage in fruits and vegetables

Over the last century, processing and packaging techniques have become advanced, microbial spoilage has become one of the major issues for degrading the quality of packaged fruits and vegetables, due to surface discoloration, water-soaked appearance, off-aroma, moisture loss, and flavour and texture changes. The main criterion for determining the shelf-life of food products has been microbiological spoilage, which includes off-flavor, sour taste formation, slimy surface, and visual microbial growth in colonies. As a result of spoilage due to microbes, fresh fruits and vegetables under controlled atmospheric conditions shrink by 30–50% and fresh-cut products packed properly will shrink by nearly 100% under such conditions (Poltronieri *et al.*, 2014) [46].

5. Sources of microbial contamination

Microorganisms found on the surface of raw products are visible and which is the most common source of microbial contamination as a result, fruits and vegetables rotting occur (Shao *et al.*, 2010) [59]. A variety of factors contribute to spoilage and decay of food, such as the oxidation of phenolic compounds by endogenous enzymes in plants (browning) or the degrading of pectin (Softening) by insects, and the chewing of food by rodents. The presence of visible parasites, such as in meat and fish, alters the flavour of the food. In addition, light can cause pigment degradation, fat degradation, or pigment production (Greening of potatoes). Microbes (Bacteria, molds, and yeasts) that eat food and metabolize it. In addition to temperature, emulsions can break when exposed to excessive heat or freezing. The oxidation of lipids by air, particularly oxygen, causes strong off-odors and flavors. Insufficient moisture can lead to cracking, crumbling, or crystallization, while excessive moisture can cause sticky, soggy, or lumpy surfaces (Del velle, 2010) [29]. Rodents and insects may cause damage that provides an entry point for growth of microbial colonies. Different temperatures, oxygen levels, and moisture levels increase the activity of endogenous enzymes (Duffy and Moore, 2017) [13].

6. Recently developed spoilage detection techniques

In modern age with the increased disease variant, people became more curious about the natural and organic nutrition. The ability to predict shelf-life all through product innovation and to ascertain the surviving shelf life of food products all through storage is critical for food business operators in food value chain (Qadri *et al.,* 2015) [43]. This has prompted the development of techniques of measuring food spoilage that are quick, accurate and verifiable. As an indirect method for detecting and quantifying microbial contamination of food, chemical techniques based on the analysis of specific chemical markers can be employed.

According to Tait *et al.* (2014) [8], microbial spoilage detection systems are increasingly being used to determine the presence and spread of microorganisms in foods. Wang *et al.,* (2016) [18] reviewed all those techniques which are used in selection of sample, their detection and then inspection of the microbial volatile organic components present in food. Despite all of the advances in the detection devices, the difficulty of microbial and biochemical mechanisms engaged in spoilage continues to pose a challenging task in creating a single quality monitoring approach for single food products (Remenant *et al.,* 2015) [4].

6.1 Biosensors

Biosensor is a device that combines bioactive content with a transducing attribute to detect the presence of a specific analyte composition of a sample. Biosensor devices incorporate a bio receptor in a suitable transducing framework and able to identify particular chemical substances (Zhang *et al.*, 2016) [7]. The following are the main components of a biosensor: (1) biologically active material: a biologically derived material is one that engages with the analyte under study, such as antibodies, enzymes, microorganisms, and so on. (2) Detector Element: A transducer, also defined as a detector element, converts biological signals into more easily measured signals such as amplified signals, optical transducers, electrochemical transducers, calorimetric transducers, and so on. (3) The signal processor is the instrument that shows the result. Biosensors are used in the food products to discover food components or the existence of microorganisms (Rustagi and Kumar, 2013) [51]. As a result of the direct interactions between the analyte and the bio element, an electric sensor that can be measured is created (Park *et al.*, 2015). Biosensors are now powerful analytical tools with various applications in the agro-food sector primarily in biotechnological equipment. Biosensor is an analytical framework for the accelerated and quantifiable detection of microbial spoilage in fruits and vegetables. In enzymatic biosensors, an enzyme catalyses a reaction in which the union of the substrate is produced in a specific region of the enzyme known as the active center, which after forming the items is retrieved and can create a new reaction cycle. Because of their processability or the capacity to isolate and purify diverse sources, enzymes were widely used as biological recognition components in the first creation of biosensors (Monosik *et al.*, 2012) [49].

This method is frequently used, for instance, with some fruit sugars, in which the enzymes used respond with the hydrolysis products of the same. Because they are stable catalyze oxide reduction reactions and oxidoreductase, glucose oxidase, horseradish peroxidase and alkaline phosphatase are the enzymes which are commercially available and most commonly used enzymes in biosensors (Ispas *et al.*, 2012) [6]. It is becoming more and more evident that Nano biosensors are a sensible way to apply the knowledge of physics, biology, chemistry, biotechnology, molecular engineering, and nanotechnology in the food analysis sector. Molecular engineering, nanotechnology, and physical sciences can all be combined to produce nanosensors with significant accuracy improvements. Microorganisms, contaminants and food freshness can all be detected and quantified using Nano biosensors (Kumar and Neelam, 2016) [16].

6.2 Electronic Nose

Nano-biosensors can identify and quantify microorganisms, contaminants, and food freshness. Electronic nose experiment was developed in the early 1980s and is basically a device made up of a range of electronic chemical sensing with incomplete sensitivity and an effective methods identification system able to recognize simplified odours. Nowadays, it is used to detect a wide range of fruits and vegetables spoilage due to its use as the "main instrument" for evaluating the smell of various products. The human sense of smell can be used for sensory evaluation; however, it is still an expensive method despite its use of the human sense of smell. The concept of the electronic nose became popular for odor analysis in several branches of food and other sectors of the economy. A nose system that mimics the structure of the human nose, while reducing its constraints, is known as the electronic nose (Jiang *et al.*, 2018) [15].

Gardner defined an electronic nose as "an instrument that consists of an array of electronic chemical sensors with incomplete sensitivity and an effective methods identification system capable of recognizing simple or complex odours" (Kalit *et al.*, 2014) [39].

There are several components of an electronic nose, including an aroma extraction system, a sensor array, control and measurement systems, and an information processing system. The aroma extraction system, also known as the sampling techniques, transports components from the samples to the sensor chamber and dramatically improves the capacity and stability of an odour sensor framework. These tools have only recently become commercially available and are still in the development stage. They are probably to have a broad area of possible approaches, including the efficient and non-invasive detection of spoilage and a variety of quality characteristics in foods. Electronic noses have enormous potential for detecting various microbial species (Huang *et al.*, 2015) [58]. In food sector, EN technology has been successfully used in the food products for quality control, performance monitoring, freshness assessment, shelf-life investigation of fruits and verification assessment across a wide range of food varieties. The electronic nose could indicate the presence of *Alicyclobacillus spp*. in all fruit juices. As little as 102 colonies forming units/ml of bacteria can be detected using the electronic nose, and the system can be used to classify contamination regardless of *Alicyclobacillus* species (Turner *et al.*, 2013) [2].

6.3 Electronic Tongue

The IUPAC defines an electronic tongue as "a multisensory framework that consists of a large number of reduced sensors and uses advanced mathematical procedures for signal processing based on pattern recognition or multivariate data analysis" (Vlasov, 2005). Electronic tongues have been used effectively to determine the theoretical and practical spoilage of several foods of concern. Quantitative determination is usually acquired from statistical concepts based on data registered with the electronic tongue's various sensors, which enables quantitative evaluations about certain physical-chemical and sensorial parameters, such as similar least squares–discriminant analysis (PLS-DA) or PLS2 regression models (Zhang and Keasling, 2011) [11].

Electronic Tongue device has become emerging technique in new era, including the application of vague and general chemical sensors in assembling the specific ion-selective electrodes and the usage of novel advanced extraction methods (Narsaiah *et al.*, 2012) [24]. In general, food is generally described as having five basic tastes: sweet, salty, bitter, sour, and umami (or delicious). ‘Kokumi’ a term that has been implemented to explain the “complexity,” “mouthfuls,” and “long-lastingness” of the food products. Sweeteners contain carbonyl groups; saltiness and sourness are made up of sodium ions; monosodium glutamate, frequently used to enhance umami taste, is composed of hydrogen ions, responsible for sourness (Ghasemi and Aghbashlo, 2018) [30].

There are numerous compounds and several natural toxins have a bitter taste. In order to provide a natural protection response, the tongue has become highly sensitive to bitterness. Another potent kokumi substance discovered was a compound comprised of the amino acids glutamine, valine, and glycine. Over the last 2 decades, multisensory processes have actively evaluated vegetable oils, particularly olive oils, and interest in vegetable oil inspection by artificial detection techniques remains high. Artificial olfaction processes or electronic noses were historically used to evaluate the aroma of vegetable oils (Perez-Lopez and Merkoci, 2011) [3]. The use of electronic tongues was significantly reduced as a result of experimental issues which are related to the required material pretreatment: for oil extraction and dilution, hydrophilic solvents are required to allow the appropriate working of electrochemical sensors used in electronic tongue system (Mutlu *et al.*, 2016) [33].

Another application of multisensory frameworks is evaluating the freshness, sweetness, and quantitative estimation of various nutritive elements as vitamins, antioxidants in fruits and vegetables (Smyth and Cozzolino, 2013) [17]. Grapes are extremely significant among fruits because they are the starting point for wine production. The assessment of phenolic antioxidants is frequently the concentrate of grape assessment. Medina-Plaza *et al.*, (2015) [5] revealed that electronic tongue comprised of Nano-composite voltammetry biosensors dependent on phenol oxidases for grape variety distinction. In a study published by Liu *et al*. (2014) [57], seven Spanish grape varieties were monitored with the use of a metallic volta-metric tongue. Wang's group used the a-Astree potentiometric e-tongue and the volta-metric metallic e-tongue to differentiate maintained licorice apricots to assess the sugar quantity in pears of various cultivars (Honeychurch and Piano, 2018) [25]. After softening in deionized water the apricots were minced and analyzed by using an electronic tongue after centrifugation. Kaczmarket *et al.*, (2019) introduced the use of a combined multi-sensor system to analyse wine spoilage when it comes into contact with air.

6.4 Smartphone-based technologies

The new era of mobile-based techniques outperforms conventional platforms, and needed minimal instruments and user involvement in terms of test frequency, control, inexpensive, ease-of-use and data management (Peris and Gilabort, 2013) [34]. Smartphone optical and spectroscopy, as well as lab-on-a-smartphone biosensors, are two types of smartphone-based food treatment modalities (Lozano *et al.*, 2015) [20]. The novel area of research describe about the significant scientific and commercial implications. Advances in chemistry, food technology, biotechnology and engineering resulted in new distinct platforms that are more transportable, cost-effective, and simple in use for food analysis than lab-based assay methods. In addition, the widespread availability of mobile phones makes it appropriate for on-site testing. The most recent advancements in smartphone-based food diagnostic technologies are discussed. These tools usually include detectors, sample processors, computer chips, batteries, software that are connected with a commercial smartphone (Piriya *et al.*, 2017) [55]. The most critical outlook of evolving the processes is integrating these elements on a small and light-weight platform which requires little power and investigations have indicated a number of promising approaches that make use of a variety of detection methods and device configurations (Shah, 2013) [22].

Table 1: General Types of Microbial Spoilage (Qadri *et al.*, 2015) [43]

Sr. No.	Spoilage	Cause	Effects	Examples
1.	Bacterial soft rot	*Erwinia carotovora*	water-soaked appearance, soft mushy consistency, often a bad odor	Potato, Tomato, Sweet potato,
2.	Grey mold rot	*Botrytis cinerea*	favored by high humidity and a warm temperature	Strawberries, Grapes
3.	Rhizopus soft rot	*Rhizopus stolonifer*	soft and mushy cottony growth of the mold	Sweet potato, Tomato
4.	Anthracnose	*Colletotrichum lindemuthianum*	defect is spotting of leaves and fruits or seed pods Beans	Pear, Mango
5.	Alternaria Rot	*Alternaria tenuis*	greenish brown turn to brown or black spots due to mold growth	Pomegranate, Tomato, Capsicum
6.	Blue mold rot	*Penicillium digitatum*	Bluish green color spores are produced	Citrus fruits
7.	Downey mildew	*Phytophthora, Bremia*	molds grow in white, wooly masses	Cucumber, pumpkin
8.	Watery soft rot	*Sclerotinia sclerotiorum*	Found mostly in vegetables	Carrots, Broccoli, Apple
9.	Stem end rots	*Diplodia, Alternaria, Phomopsis, Fusarium*	Involve the stem end of fruits	Orange, grapes
10.	Black mold rot	*Aspergillus niger*	Color turns Dark brown to black	Onions

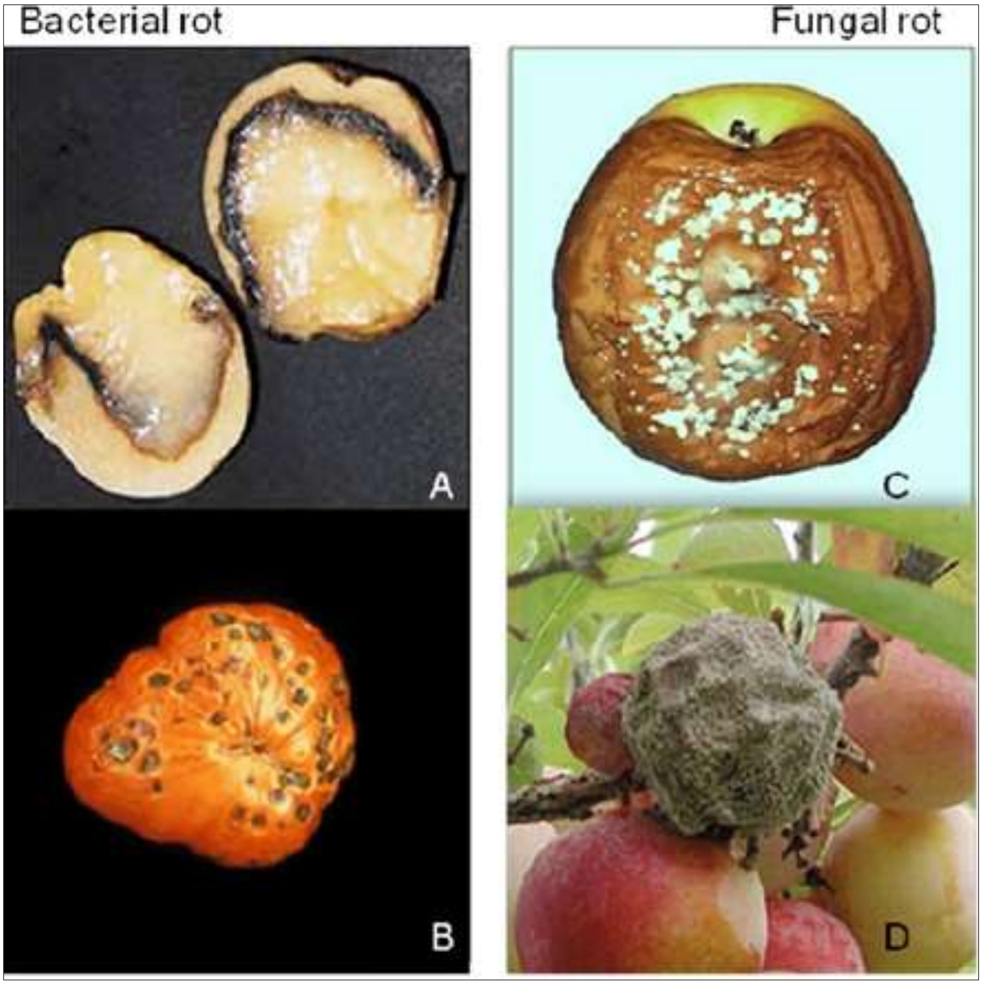

Fig 1: Fresh fruits and vegetables spoilage due to bacterial and fungal rot (Qadri *et al.*, 2015) [43]

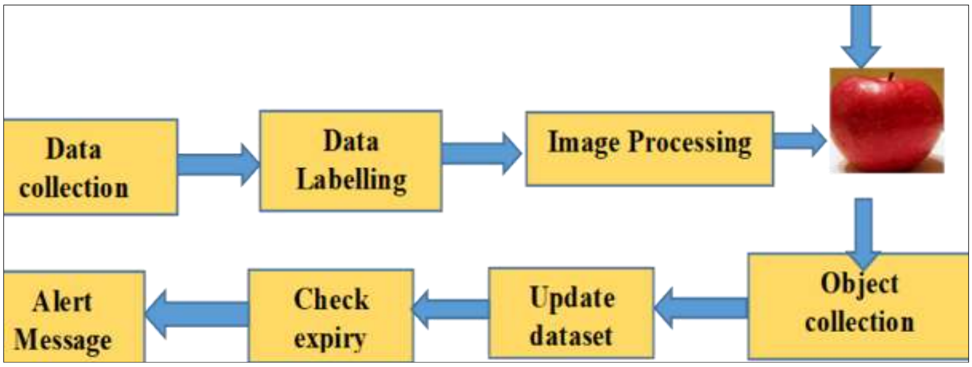

Fig 2: Design of fruits and vegetables spoiled detection system

Fig 3: Biosensor for monitoring the quality of fruits (www.wikipedia.com)

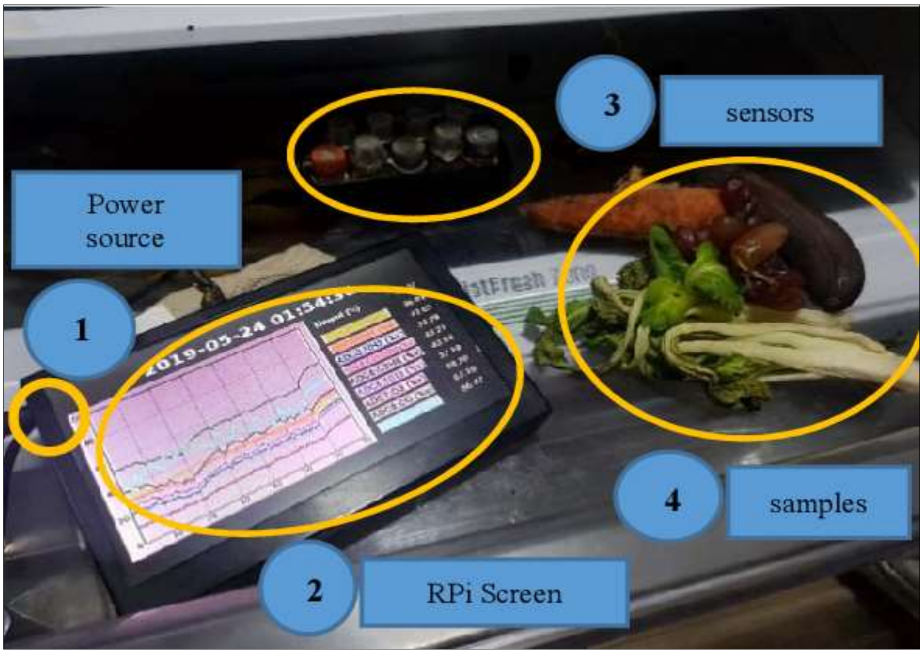

Fig 4: E-Nose prototype actual setup inside refrigerator (www.wikipedia.com)

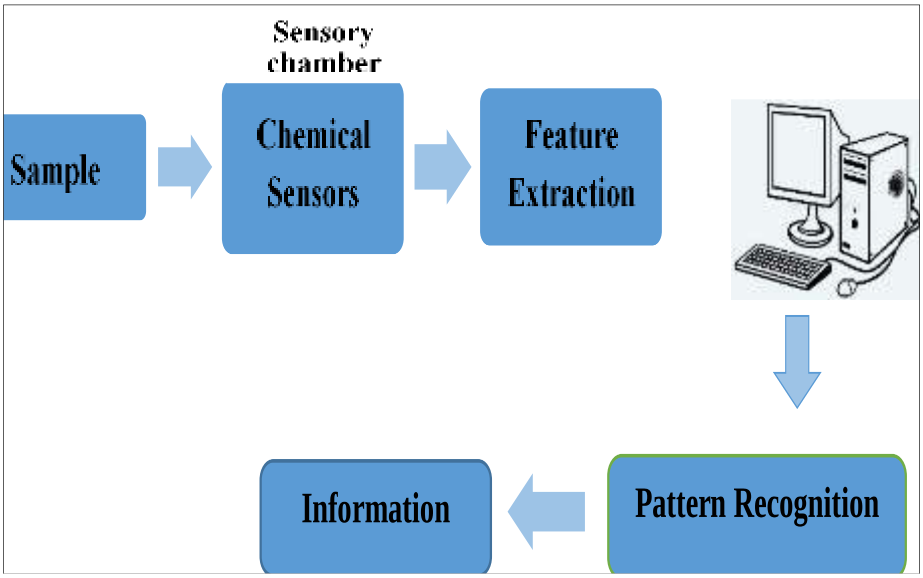

Fig 5: General Scheme of an electronic tongue system

Fig 6: Detecting spoilage with smartphone technology (www.wikipedia.com)

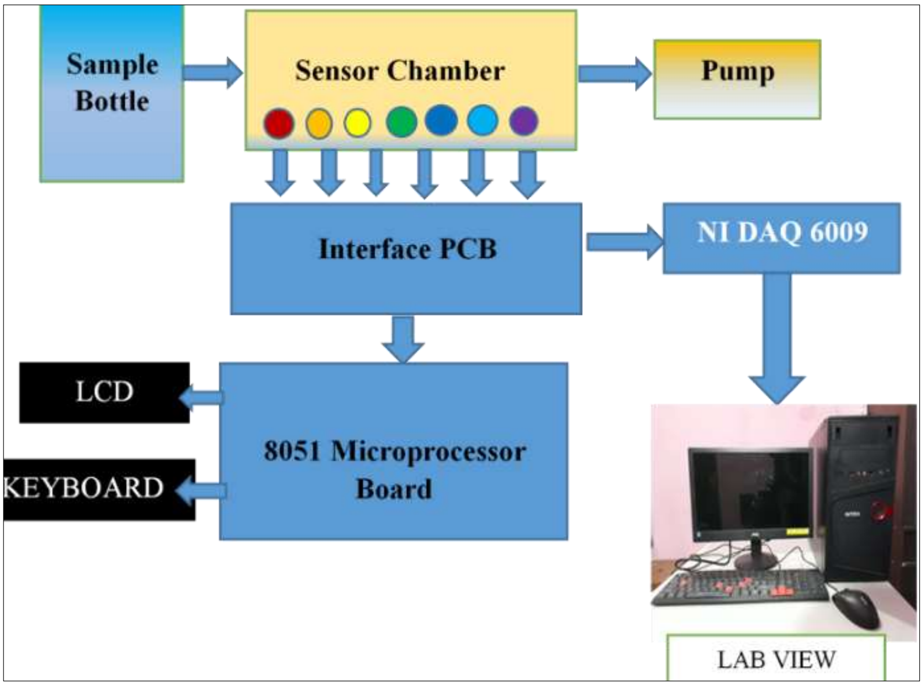

Fig 7: Block diagram of an electronic nose system.

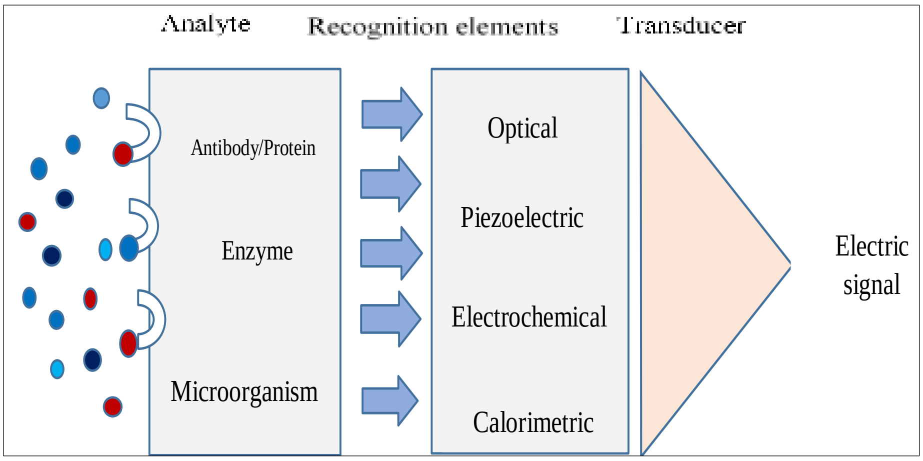

Fig 8: Biosensor detection scheme

Conclusion and Future Trends

The use of chemical, biological sensors and indicator labels in active and smart packaging, the advancement of approaches to evaluate the quality of fruits, vegetables and food products, is a growing area of research. The most effective sensors to date have been used to detect volatiles such as amines and ethylene. Many food biosensors just require food-sample processing in their current state of development. Future advancements must focus on lowering the limit of detection and raising the ability to compute the markers on single contacting with the material. There is a need in the bio sensing field to even further facilitate detection techniques in order to avoid the use of multiple steps or reagents, reduce costs, and miniaturize the sensor. Another task that must be addressed is improving the stability of the biological element in biosensors, their design features and procedures in various operational times all through storage of fruits and vegetables in package, particularly for systems that integrate sensitive bio recognition elements such as enzymes.

This review outlined the advanced spoilage detection methods for fruits and vegetables such as electronic nose, electronic tongue, biosensors, and smartphone-based technologies are some of the promising trends for rapid spoilage detection. In future, use of these techniques on wide scale would be a new trend of spoilage detection in fruits, vegetables and various other food products that improve the microbiological quality while having the lowest impact on the freshness, organoleptic properties and quality of foods.

Conflicts of Interest

The authors confirm that there is no conflict of interest to declare.

Declarations

This review article has not been submitted anywhere else and follows the research ethics.

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