RECENT ADVANCES IN THE USE OF NANOMATERIALS AS NANOBIOSENSORS IN THE FOOD AND AGRICULTURE SECTORS

Abstract

The key issues preventing the agricultural and food sectors from remaining sustainable include the growing global population, depleting land, and rising production costs. Natural resources can be used more effectively based on the use of nanobiosensors. To address the enormous need for foods and agricultural items for a constantly growing population, nanotechnology research trends are being implemented in almost every aspect of science. Nanosensors are employed in the food inspection process to support the integrity of the food packaging's external and internal conditions. Electrochemical nanosensors based on carbon nanotubes have been developed to identify particles, hazardous pollutants, organic chemicals, herbicides, excessive chemical use, and so on. Present study discusses a variety of topics relating to nanosensors and nanobiosensors that are currently being developed and have great promise for use in the industry sectors for agriculture and food. In order to give both academic and industrial researchers insightful information, the benefits and limitations are also explored. To advance the study of the sustainable development of agriculture facilitated by nanotechnology, future research directions have been outlined.

Keywords: Nanomaterials, Nanobiosensors, Agricultural & Food industries

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I. INTRODUCTION

The field of study known as nanostructures is involved with the emergence, characterization, operation, as well as utilisation in nanostructured materials for a wide range of applications [1,2]. Nanostructured materials range in size from one to hundred nm and can be further modified [3]. The size reduction to the nanoscale region enhanced the surface area to (and associated interface energy), the ability to adsorb, and physiological performance [4]. Furthermore, the chemical and physical composition of nanomaterials, including diffusivity, strength, colour, and solubility, in addition to optics, magnetic, and thermodynamic characteristics, are discussed, have significantly improved [[5], [6], [7]]. The reduced density and chemical, mechanical, and kinetic stability of nanoparticles are other distinctive qualities [8]. Modern nanostructure materials and nanocomposites significantly outperform their macro/bulk counterparts in terms of applications and performance. Nanotechnology has an impact on many industries, including the environment, agriculture, medicine, and food. It is one of the agri-food industry's quickest-emerging research subjects. Global production of food with improved quality, nutritional content, and safety has expanded dramatically as a result of nanotechnological breakthroughs [9]. Recently, the demand for nanomaterials has increased rapidly along with the market for nanotechnology [10].

Nanomaterials have been produced via a variety of techniques, including chemical, physical, and organic methods [11,12]. Biosynthesized nanoparticles hold considerable promise for long-term technical applications in the nutritional and agribusiness sectors, such as improved product safety and quality, decreased fertiliser usage, and enhanced nanoscale utilisation of nutrients from land. Farming, innovative systems for distributing agricultural chemical products like pesticides and chemicals, early disease detection in foodstuffs, system-wide collaboration for preparing meals, appearance, and surveillance, and ecological drainage systems all have potential for development [13,14]. Every one of these aspects possess an effect on how food and other agriculturally based products are produced, which are significant driving forces. A number of its considerable benefits for buyers, manufacturers, producers, natural systems, and the community, this nanomaterial is expected to take prominence in the near future. Researchers and experts are looking for alternative, intense, and ecologically safe ways to prevent plant diseases [15]. As a cheaper alternative to chemical pesticides, metal nanoparticles have become more and more popular [16]. This is due to technological developments that have reduced the cost of their products.

Applications of the unique characteristics of nanoparticles have been used to enhance current in-use conventional technologies. The creation known as nanobiosensors, which combine biosensors with nanomaterials, has increased the scope of environmental applications for which they can be used. As a result, the production of genuine, real-time sensing nanobiosensors that make use of special characteristics of nanomaterials in addition to extremely particular biological components is a superior choice for rapid, prompt detection and identification of illnesses of plants [17]. This chapter focuses on a number of diversified applications of widely utilized nanobiosensors to address the growing need for nutrient-dense food and discover solutions to several agricultural difficulties. There are numerous uses for nanotechnology in food production, such as packaging, nutrient delivery, mineral/vitamin enrichment, food processing, and nutraceuticals. Additionally, it has been claimed that produced nanoparticles can support testing, keep track of contamination, and provide higher foodstuff is nutritious and high-quality [18]. The packing of foods is unquestionably a crucial

and difficult aspect of ensuring the long-term stability and quality of food goods. Nanocomposites solve the problems associated with conventional packaging by providing improved antibiotics destruction, thermal energies barrier, and material properties, as well as a nanosensing feature to alert people regarding circumstances (temperature, oxygen, humidity, harmful substances, etc.) as well as the quality of food items while employed as packing thin films [19]. The most recent uses of nanobiosensors in food items and crop production sectors are critically examined in this chapter, along with various challenges they have encountered.

II. NANOMATERIALS AS NANOBIOSENSORS

Synthetic receptors have replaced original biological components to replicate functions with more quick and precise detection ranges [20]. By integrating biological probes with nanoparticles such as magnetic, metal-based, quantum dot particles, oxide of graphene, and nanotubes of carbon, analysers can be recognised. Several high-tech material types have been used in nano-sensing applications to make nanobiosensors (Fig. 1). Nanosensors have been developed Carbon nanotube-based tiny substances, especially single- and multiwalled nanotubes made of carbon, are being used. Chopade et al. describe nano-biosensors based on carbon nanotubes for detecting toxic metals in water-based environments [21].

Fullerenes, titanium, and silicon oxides are among the other materials used [22]. Zeolites, chitosan, and polyacrylic acid are examples of polymers that can be utilised for encapsulation. Because of their safety qualities, Certain nanoparticles that are metallic, notably the precious metals gold and silver, can be used in nanobiosensors. Gold and silver-based compounds are the most commonly utilised materials used as nanobiosensors to detect pathogenic microbes and contaminants in the water and food supply [23].

Metallic component-based nanobiosensors can be utilised to detect pathogenic contaminants due to the availability of safer alternatives in food products [24]. Fluorescence measurement is another well-liked technique to develop nanobiosensors. Fluorescence-based detection techniques could be basic [25]. Other methods, such as modular designs, one fluorophore, and two fluorophores, have been employed to develop fluorescent-based biosensors. Zinc oxide (ZnO) is the second most prominent metallic alternative employed in the construction of nanosensors. Nanobiosensors based on light emitting diode (LED) technology are used to identify reactive substances in materials used to package food. ZnO is famous for its excellent a catalytic strength, strong isoelectric instance, and significant ability to absorb [26]. In place of metals and other elements, nanobiosensors have been produced with biological components. One such material is lipid-based bilayer membranes.

A significant amount of phospholipid membrane-based nanobiosensors are being produced and have been used to differentiate between metallic substances, toxins, as well as microorganisms. Technical challenges including reduced stability and sensitivity to damage from sources other than electrolyte solutions are connected. The performance of membranes can be enhanced by increasing their stability using glass, zinc oxide, and graphene [27].Agricultural wastes are a commonly available and affordable option that can be used for producing novel nanobiosensors materials. Nanocellulose fibres can now be produced, which makes it possible to use these materials in a variety of applications [28].
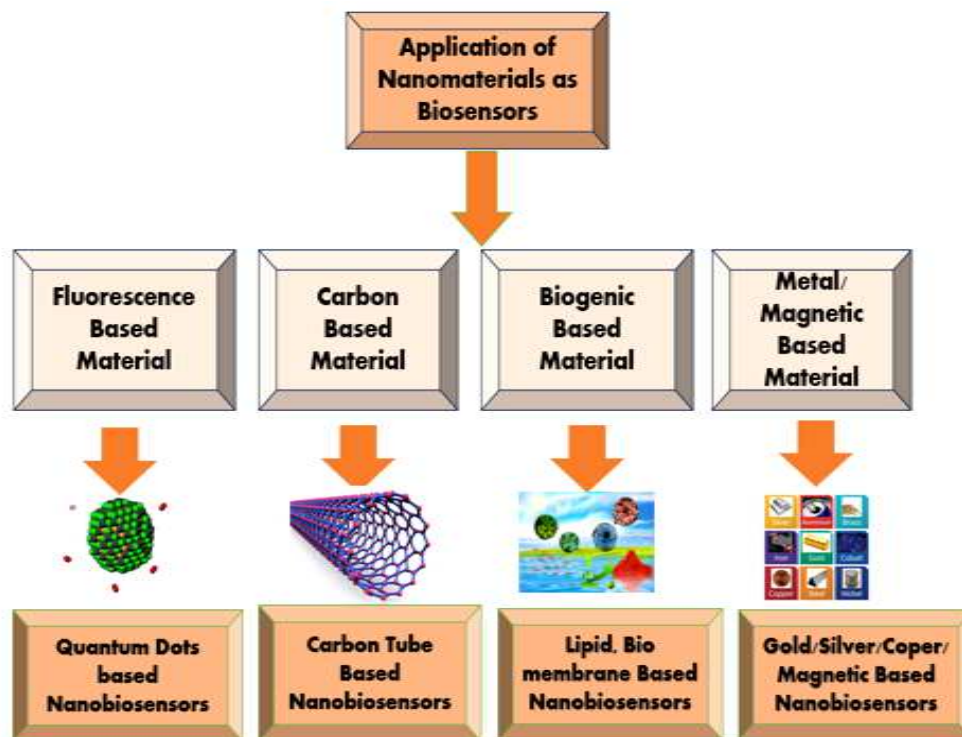
Figure 1: Numerous materials used in nano sensing applications for the manufacture of nanobiosensors

III. APPLICATIONS OF NANOBIOSENSORS IN THE AGRICULTURAL INDUSTRY

Many different forms of Nanocapsule and nanodevices are currently used in the agricultural sector to identify and treat crop diseases, because nanobiosensors can be focused on a specific location of concern,. Treatment of industrial effluent, water filtration, and nutrient absorption are some other significant uses of nanobiotechnology [29-31]. Targeted management of nanocomponents reduces damage to undesired plant locations and regulates the environment-harming effects of chemical fertilisers and pesticides. Nanomaterials and nanobiosensors have special chemical and mechanical features that make them electrochemically active. Such nanobiosensors might be useful for cultivating as well as breeding plants and animals**.**

Nanosensors are an effective instrument for detecting nutrient shortages as needed, toxicity, animal and Plant infections and managed nutritional status for better health and safety of food [32]. They can assist in increasing agricultural productivity more effectively by managing pesticides, fertilisers, and irrigation with minimal risk of waste. Bionanosensors can detect ecological shifts; mixing parts of organisms Incorporating nanomaterials and particles inside detectors provides the capability to improve selectivity and ultimately cut response times for identifying potential risks [33, 34]. For instance, many kinds of biosensors have been created for the precise identification of the cyanobacterial microcystins, toxicity, which is a serious threat to agricultural goods [35].

The phenolic phytohormone salicylic acid enhances a plant's ability to grow, transpire, and perform photosynthesis, among other functions. There is a need to determine the concentrations of salicylic acid in plants because it is a significant plant component. For this reason, gold electrodes coated with nanoparticles of copper were used in nanobiosensors [36]. Copper nanoparticles identify the chemical salicylic acid during electrocatalytic oxidation to determine its electrolytic nature. Using gold nanoelectrode and copper nanoparticles is the most accurate method for determining salicylic acid levels in oilseeds infested with the fungus Sclerotinia sclerotiorum [36]. Triazophos (an insecticide) was detected in postharvest crops and vegetables utilising nanobiosensors and an Au nanoparticle-deposited carbon nanotube electrode [37]. Nanoparticles of silver (Ag) and gold (Au) were utilized in nanobiosensors to assess the amount of an organophorous insecticide found in the atmosphere or after harvesting foodstuff [38]. surface-enhanced Raman scattering spectrum has been utilized for recognising insecticides in food products and the natural environment in a number of analytical applications in the chemical and agricultural industries. A monolayer of specially designed Ag nanoparticles was utilized in a recent work to boost Laser sensitivity for detection and to determine the quantity of methyl parathion [39].

Several industrialized nations' governments continue to invest significantly in cutting-edge nanotechnology research and advancement in a variety of fields, especially the nutrition and farming sector. Nanotechnology has clearly had a big influence on strengthening the economic condition of countries such as the The USA, Europe, China, the Soviet Union, and Korea are all represented. Other Asian countries, such as Vietnam and the country of India, are attempting to boost their yearly expenses towards cutting-edge nanotechnology development and study in order to improve their global market competitiveness and meet financial requirements [40]. The uses of nanosensors for the commercial security of products are listed in Table 1.

IV. APPLICATIONS OF NANOBIOSENSORS IN THE FOOD INDUSTRY

Metallic nanoparticles have a wide range of potential applications in food technology due to their unique shape- and size-dependent characteristics. Metallic nanoparticles are suitable for usage in association with enzymes, medicines, the ligands antigens, colorimetric and fluorometric agents, and various kinds of biomaterials due to their visible, biological, mechanical, antimicrobial, and electrochemical capabilities [46]. As a result, these nanoparticles can be used in a variety of applications, such as improved diagnostic assays, radiation, thermal ablation, gene and drug delivery, optical imaging, efficient antibacterial activity, and hazardous material cleanup [47, 48]. By detecting microbial deterioration of food quality as well as pollutants, nanoparticles of metallic material have significant effects on the manufacturing and consumption of food and a capacity to react promptly to infectious agents, processing concerns, insecticides, and poisonous wastes.

Au nanoparticles' emission spectra are influenced by local surface plasmon resonance with regard to comes to optical properties. When the conduction band is coherently excited, electrons cause an oscillating electromagnetic field to oscillate on the positive metal-lattice. The mixing and agglomeration of gold nanoparticles in the nanosensors or nanobiosensors that could increase the ability to detect of adjacent SPR (surface plasmon resonance) by a factor of two to ten, as well as surface-enhanced Raman scattering by a factor

of 106 to 109 [49]. Gold nanoparticles have been discovered to have strong specific SPR absorption as well as low absorption coefficients in the visible wavelength region, and it frequently exhibits a change in colour from an intense red to navy blue after reaching the association phase [50].

A branched polyethyleneimine-based nanosensor based on Ag nanoparticles was used to detect pollutants including the cancer-causing nitrile. Under low pH conditions, nitrite and H_2O_2 (hydrogen peroxide) produce peroxynitrous acid, which causes Ag nanoparticles to aggregate. Fluorescence quenching was linked to nitrite concentrations below the 100 nM limit of recognition [51]. Ochratoxin-A, a fungicide generated by agricultural and food toxins or pollutants Aspergillus and Penicillium, is detected using Au nanoparticle SPR. To detect the ochratoxin-A pathogen, thiolate aptamers which are covalently attached to gold nanoparticles via an Au-S (gold-sulphur) connection [52]. This ability of antioxidant substances to prevent the illumination of gold nanoparticles is being demonstrated to be associated with important spectral diagnostic techniques in terms of quick responses and higher biological suitability. This methodology is used to assess the antioxidant content of professionally available and utilized juices of the fruit [53].

Due to their unique characteristics, including their small dimension, electromagnetic and thermal conduction, capacity, as well as specific area of coverage. C-nanotubes have a significant potential for use in the fabrication of small biosensors for a variety of possibilities in nano biosensor technological advances. [53]. An example of a carbadox indicator residue is quinoxaline-2- carboxylic acid, which has potent mutagenic and carcinogenic effects and is utilised as an additive in foods like fish, chicken, and pork [50]. A single-wall C-nanotube was designed to detect D-fructose in different beverages such as juices from fruits, sugar, flavoured beverages, energizers, and so on. [50]. The use of a polymer (osmium redox polymer as redox mediator) to transfer electrons between bound glucose dehydrogenase enzymes and their substrates was used in the production of nanobiosensors as based on encapsulated glucose reductase proteins.

The nanoscale revolution has the ability to bring about significant advancements in food packaging, including mechanical qualities, The identification of pathogens, as well as cutting-edge packaging solutions that protect foodstuff integrity and hygiene. The use of an aluminium nanolayer on top of the preservation of food is an outstanding illustration of the way nanostructures may be used. is currently serving in industries related to food manufacturing. Additionally, a lot of research is being done on biodegradable nanocomposites that are used in food packaging. By applying high shear to carbohydrates and clay fillers, exfoliated clay layers can be used to shape films. Because they make it more difficult for water to infiltrate the films, these kinds of films function as particularly effective moisture barriers. These kinds of materials can also be used to create very significant gains in film strength. Two of the most investigated biodegradable matrices are starch and chitosan [55]. Unique food packaging materials with colour-changing capabilities can be developed through photonic crystals. [55, 56]. The majority of the analytical methods involve measuring To examine changes in optical characteristics, adjust the mass resonance frequency with a cantilever, customised optical nanoparticles as or silver and gold nanoparticles equipped with genetic material (DNA) [Table-1].

Table 1: Nanobiosensors are of various kinds have been utilised in agriculture and the food and beverage production.

Nanobiosensors	Kind of Nanomaterial	Uses	Reference
fluorescent-based nanosensor	Quantum dots	Pathogen noting	[41]
Surface plasmon resonance	carbon nanotubes	Cymbidium Mosaicvirus identification	[42]
Pesticide detection nano biosensor	Graphene based polymers	Pesticide detection	[43]
Smart Nano biosensor	Copper and Zinc Oxide	Enhance germination in Plants	[44]
AChE biosensor	DNA based biosensor	Detection of palm eater	[45]
Nanosensor	Carbon nanotubes	Used in detection of arsenic, copper and mercury	[57]
Melamine detection	DNA-Cu-NPs	Used in finding melamine in milk	[58]
SPR based sensor	Carbon nanomaterial	Aflatoxin detection in peanut and rice	[59]
Nanosensor	ZnONPs	Used in bacteria detection	[60]
ZnONPs	Antibody	Used in detection of Microbial infections	[61]

V. CONCLUSION AND FUTURE PERSPECTIVES

Many nanobiosensors are being used in the agri -food sectors. is used in developing of the nanosensors used in food analysis. The use of nanosensors that incorporate Raman spectroscopy for food forensic science should also be emphasised. Food forensics is a process for conducting investigations into the origin, adulteration, contamination, and even the presence of dangerous substances in food. In is employed in the development of nanosensors for analysis of food. It is particularly essential that we highlight the significance of nanosensors that include a Raman spectroscopy technique to detect food scientific research. Food forensics is the process of investigating the source, tampering contamination and as well as existence of contaminants in food. In Things can be used as nano tracers on their own or in conjunction with packaging to track the history of food products and determine whether they are still within acceptable quality limits at any given time. One example is the use of nanosensors or nanobiosensors in food packaging to detect microbe growth and colour changes as an edge level is approached. Nanosensors combined with process control to monitor storage conditions to prevent food contamination will be important in the future [22, 62]. The field of nanotechnology life sciences, and the field of chemistry these domains, the employment of nanosensors can complement the strategy while also allowing the exploration of diverse analytes, beginning with macro food and progressing to proteins, carbohydrates, lipids, dyes, pigments, or additives.

We anticipate that the development of novel nanosensors, as discussed in this chapter, will improve the production of accessible and economical nanomaterial-based detecting systems. However, the full potential of nanobiosensors in the food and agriculture industries has yet to be exploited. This chapter focused on the many components and uses of nanobiosensors in the sectors of agriculture and food processing.

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