**Recent Advances in the Use of Nanomaterials as Nanobiosensors in the Food and Agriculture Sectors** **Vijay Devra**

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**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 meet the huge demand for foods and agricultural goods for a constantly expanding population, the blooming research trends of nanotechnology are being implemented in nearly every field of science. Nanosensors are employed in the food inspection process to support the integrity of the food packaging's external and internal conditions. Carbon nanotube-based electrochemical nanosensors are being developed to detect ions, poisonous heavy metals, organic compounds, pesticides, excessive fertiliser use, etc. This 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.

Key words: Nanomaterials, Nanobiosensors, Agricultural & Food industries

 **I. Introduction**

The field of study known as nanotechnology is concerned with the development, characterisation, operation, and use of nanostructured materials for a variety of utilization [1,2]. Materials with nanostructures range in size from 1 to 100 nm and can be further modified [3]. The surface to volume ratio (and associated surface energy), adsorption capacity, and biological effectiveness were all improved by the size reduction to the nanoscale region [4]. Additionally, the physical and chemical properties of nanomaterials, such as their diffusivity, strength, colour, and solubility, as well as their optical, magnetic, and thermodynamic properties, 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].

 Many different processes, including physical, chemical, and biological ones, have been used to synthesise nanomaterials [11,12]. Biosynthesized nanoparticles have great promise for sustainable technological applications in the food and agriculture sectors, including increased food quality and safety, reduced agricultural inputs, and enhanced nanoscale nutrient absorption from the soil. The potential for growth is seen in a number of fields, including agriculture, a smart system for distributing agrochemicals like pesticides and fertilizers, early disease detection in food materials, system integration for food processing, packaging, and monitoring, and natural reservoir management [13,14]. All of these factors have an effect on how food and other agriculturally based products are produced, which are significant driving forces. This nanomaterial is projected to take centre stage in the near future due to its significant benefits for consumers, producers, farmers, ecosystems, and society 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 better option for the quick, early diagnosis, and detection, of plant diseases [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 food quality and safety [18]. The packing of foods is unquestionably a crucial and difficult aspect of ensuring the long-term stability and quality of food goods. By offering enhanced antimicrobial, degradation, thermal, barrier, and mechanical properties as well as a nanosensing feature to alert consumers about conditions (temperature, gas, moisture, contaminants, etc.) and the safety of food items when used in packaging films, nanocomposites solve the issues with conventional packaging [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]. Analytes can be detected by combining biological probes with various nanoparticles such as magnetic, metallic, quantum dots, graphene oxide, and carbon nanotubes. Several high-tech material types have been used in nano-sensing applications to make nanobiosensors (Fig. 1). Nanosensors have been developed using carbon nanotube-based nanomaterials, specifically single- and multiwalled carbon nanotubes. Chopade et al. report on carbon nanotube-based nano-biosensors for detecting heavy metals in aquatic 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 metallic nanoparticles, primarily consisting of silver and gold, can be employed for nanobiosensors. The most common materials used in food nanobiosensors to detect pollutants and pathogens in food and water are gold and silver-based compounds [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, which are used to detect free radicals in food packaging materials, are based on light emitting diode (LED) technology. The most notable properties of ZnO are its high catalytic power, high isoelectric point, and high adsorption capacity. [26]. In place of metals and other elements, nanobiosensors have been produced with biological components. One such material is lipid-based bilayer



**Fig.1Numerous materials used in nano sensing applications for the manufacture of nanobiosensors**

membranes. The vast majority of lipid membrane-based nanobiosensors have been developed and used to distinguish between metals, poisons, and microbes. 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].

**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 and nanoparticles into sensors has the potential to boost sensitivity and, ultimately, shorten response times for detecting possible hazards [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. Au electrodes coated with Cu nanoparticles (copper nanoparticles) were employed in nanobiosensors for this purpose [36]. Cu nanoparticles detect the electrocatalytic oxidation of salicylic acid to identify its electrochemical nature. An Au nanoelectrode and Cu nanoparticles are the most accurate approach to evaluate 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 a C-nanotube (carbon nanotube) electrode modified with Au nanoparticle deposition [37]. Silver (Ag) and gold (Au) nanoparticles were used in nanobiosensors to assess the amount of an organophorous type of pesticide present in the environment or postharvest food [38]. In numerous sectors of analytical chemistry and the agricultural industry, SERS (surface-enhanced Raman scattering spectrum) has been used to identify pesticides in both food and the environment. In a recent study, a monolayer of specially engineered Ag nanoparticles was used to improve Raman detection sensitivity and to identify the concentration of methyl parathion [39].

 Several industrialized nations' governments continue to invest significantly in cutting-edge nanotechnology research and development in a range of disciplines, including the food and agriculture industries. Nanotechnology has clearly had a big influence on strengthening the economic condition of countries such as the United States, China, Germany, Russia, and Japan. Other countries, such as Taiwan and India, are seeking to increase their annual expenditures for cutting-edge nanotechnology research and development in order to improve their competitiveness in the global market and meet financial requirements [40]. Table 1 lists the applications of nanosensors for agricultural product safety.

**IV Applications of nanobiosensors in the Food Industry**

 Due to their unique shape- and size-dependent properties, metallic nanoparticles have a wide range of potential uses in food technology. Because of their optical, chemical, mechanical, antibacterial, and electrical properties, metallic nanoparticles are appropriate for utilization in conjunction with enzymes, medications, ligands, antibodies, colorimetric and fluorometric agents, and other types of biomolecules [46]. As a result, these nanoparticles can be employed for a wide range of applications, including enhanced diagnostic assays, radiation, thermal ablation, gene and medicine delivery, optical imaging, efficient antibacterial activity, and hazardous material cleanup [47, 48]. Metallic nanoparticles have a substantial impact on food production, consumption, and the ability to respond quickly to pathogens, packaging issues, pesticides, and hazardous residues by detecting microbial deterioration of food quality as well as contaminants.

 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 aggregation of Au nanoparticles in nanosensors or nanobiosensors is projected to drastically increase the sensitivity of nearby surface plasmon resonance (SPR) by a factor of two to ten, as well as surface-enhanced Raman scattering by a ratio of 106 to 109 [49]. Strong specific SPR absorption, as well as extremely high reduction coefficients in the visible wavelength range, have been found in Au nanoparticles, and it often exhibits a color change from deep red to blue after attaining 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 H2O2 (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. Thiolated aptamers are covalently bonded to Au nanoparticles via an Au-S (gold-sulfur) linkage to detect the ochratoxin-A pathogen [52]. The capacity of antioxidant substances to protect the fluorescence of Au nanoparticles has been proven to be one of the key spectroscopic detecting methods in terms of rapid responses and higher biocompatibility. 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 size, high electrical and thermal conductivity, high strength, and high specific surface area, C-nanotubes have a significant potential for use in the development of nanobiosensors for a variety of applications in the field of nanobiosensors technology [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]. For the purpose of detecting D-fructose in various liquids, including fruit juices, honey, soft drinks, energy drinks, etc., a single-wall C-nanotube was developed. [50]. The development of a nanobiosensors based on immobilised fructose dehydrogenase enzymes involved the use of a polymer (osmium redox polymer as redox mediator) to transport electrons between the immobilised fructose dehydrogenase enzymes.

 The nanoscale revolution has the ability to bring about significant advancements in food packaging, including mechanical qualities, pathogen identification, and leading-edge packaging methods that ensure foodstuff purity and security. The use of an aluminium nanolayer on top of food packaging is a good example of the role nanotechnology is currently serving in food sector 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 changes in mass resonance frequency with a cantilever, functionalized plasmonic nanoparticles, or gold and silver nanoparticles loaded with DNA to evaluate changes in their optical properties [Table-1].

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| **Table 1 - Different types of nanobiosensors used in agriculture and Food Industry**  |
| **Nanobiosensors** | **Type of Nanomaterial** | **Applications** | **Reference** |
| fluorescent-based nanosensor | Quantum dots | Pathogen noting | [41] |
| Surface plasmon resonance | carbon nanotubes | Cymbidium Mosaicvirus Detection | [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 agriculture and food industries. They can be employed as nano tracers alone or in conjunction with packaging to track the history of food products and evaluate if they are still within acceptable quality parameters at any particular moment. The use of nanosensors or nanobiosensors in food packaging to detect microbe growth and colour changes as an edge level is approached is one example. Nanosensors used in conjunction with process control to monitor storage conditions will be useful in the near future to prevent food contamination [22, 62]. Nanotechnology has been proven in the agriculture business to raise production, improve soil quality, encourage plant development, and give an effective monitoring system for monitoring storage conditions, which will be used in the near future to avoid contamination of food [22, 62]. A combination of nanotechnology, biology, and chemistry 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 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 innovative nanosensors, as highlighted in this chapter, will increase the manufacture of accessible and cost-effective nanomaterial-based sensing systems. The entire potential of nanobiosensors in the food and agricultural industries, however, has yet to be realised. This chapter largely explored the many parts and applications of nanobiosensors in the fields of food and agriculture.

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