## **Recent Developments in the use of Nanomaterials as Nanobiosensors in the agricultural and Food industries**

 **Vijay Devra**

**Department of chemistry**

**Janki Devi Bajaj Government Girls college, Kota, 324001, Rajasthan, India**

**Email- v\_devra1@rediffmail.com**

**Abstract**

The main challenges to the sustainability of the agricultural and food industries 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 chapter discusses a variety of topics relating to nanosensors and nanobiosensors that are currently being developed and have great promise for use in the food and agricultural industries. 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, management, and use of nanostructured materials for a variety of applications [1,2]. Materials with nanostructures range in size from 1 to 100 nm and can be further modified [3]. The size reduction to the nanoscale range enhanced the surface to volume ratio (and related surface energy), adsorption capacity, and biological effectiveness [4]. Furthermore, there has been a substantial improvement in the physical and chemical characteristics of nanomaterials, such as their diffusivity, strength, colour, and solubility, as well as their optical, magnetic, and thermodynamic properties [[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 a huge promise in green technology for improving quality of life through applications in the Food and Agriculture fields, such as enhanced food quality and safety, decreased agricultural inputs, and improved nanoscale nutrient absorption from the soil. Agriculture, a smart system for delivering agrochemicals like pesticides and fertilisers, early disease detection in food materials, system integration for food processing, packaging, and monitoring, and natural reservoir management are all areas with potential for expansion [13,14]. The production of food and other agricultural-based goods, which are important driving forces, is impacted by all of these aspects. With considerable advantages for consumers, producers, farmers, ecosystems, and society, this nanomaterial is anticipated to become a crucial agenda item in the not-too-distant 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 special properties of nanoparticles have been employed to improve conventional technologies already in use. The development of so-called nanobiosensors, which incorporate biosensors with nanomaterials, has improved their detection capacities for a variety of environmental applications. Therefore, the development of reliable, real-time sensing nanobiosensors that make use of unique properties of nanomaterials in combination with extremely specific biological components is a preferable choice for the rapid, early diagnosis and detection of plant illnesses [17]. In order to address the growing need for nutritious food and find solutions to numerous agricultural problems, this chapter focuses on a variety of diversified applications of nanobiosensors that are widely used. Numerous applications of nanotechnology in the food trade exist, including nutrient delivery, mineral/vitamin enrichment, food processing, nutraceuticals, and packaging. It has also been reported that generated nanoparticles can aid in testing, monitor contamination, and guarantee greater quality and safety of food goods [18]. Assuring the long-term quality and safety of food products, food packaging is without a doubt an important and challenging component. When used in packaging films, nanocomposites address the problems with conventional packaging by providing improved 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 products [19]. In this chapter recent applications of nanobiosensors in agricultural and food industries are critically discussed along with their challenges and perspectives.

**II. Nanomaterials as Nanobiosensors**

In order to simulate functions with more rapid and precise detection ranges, synthetic receptors have taken the place of original biological components [20]. It is possible to detect analytes by combining biological probes with various nanoparticles, such as magnetic, metallic, quantum dots, graphene oxide, and carbon nanotubes.

Numerous high-tech material types have been employed in nano sensing applications for the manufacture of nanobiosensors (Fig. 1). Carbon nanotube-based nanomaterials, specifically single- and multiwalled carbon nanotubes, have been used to develop nanosensors. Carbon nanotube-based nano-biosensors for detecting heavy metals in the aquatic environment report by Chopade et al [21].

 Various additional materials are also employed, including fullerenes, titanium, and silicon oxides [22]. Some polymers that can be used for encapsulating include zeolites, chitosan, and polyacrylic acid. Different metallic nanoparticles, mostly composed of silver and gold, can be used for nanobiosensors because of their safer properties. Gold and silver-based materials are most frequently utilised in food nanobiosensors to detect contaminants and pathogens in food and water [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. The second important metallic alternative used in the development of nanosensors is zinc oxide (ZnO). Nanobiosensors, which are used to detect free radicals in the materials used to package food, are buil

t on the technology of light emitting diodes (LEDs). The most remarkable characteristics of ZnO include its high catalytic power, high isoelectric point, and strong 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. 1 Numerous materials used in nano sensing applications for the manufacture of nanobiosensors**

membranes. The majority of lipid membrane-based nanobiosensors were developed and implemented for determining among metals, toxins, and microorganisms. Technical problems 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 detect and treat plant illnesses because nanobiosensors can be targeted to a specific site of interest. 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 diseases, and controlled plant health for increased food safety and quality [32]. They can assist in increasing agricultural productivity more effectively by managing pesticides, fertilisers, and irrigation with minimal risk of waste. The biological organism in bionanosensors can detect environmental changes; incorporating elements of organisms and nanoparticles into sensors has the potential to increase sensitivity and ultimately reduce response times for detecting potential issues [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 use, Au electrodes coated with Cu nanoparticles (copper nanoparticles) were used in nanobiosensors [36]. Cu nanoparticles determine the electrochemical nature of salicylic acid by detecting the electrocatalytic oxidation of salicylic acid. The most accurate way to measure salicylic acid levels in oilseeds contaminated with the fungus Sclerotinia sclerotiorum is with an Au nanoelectrode and Cu nanoparticles [36]. Triazophos (an insecticide), which was initially present in postharvest crops and vegetables, was identified using nanobiosensors and a C-nanotube (carbon nanotube) electrode modified with a deposition of Au nanoparticles [37]. In order to determine the amount of an organophorous form of pesticide present in the environment or postharvest food, silver (Ag) and gold (Au) nanoparticles were utilised in a nanobiosensors [38]. SERS (surface-enhanced Raman scattering spectrum) has been used to detect pesticides in both food and the environment in several fields of analytical chemistry as well as in the agricultural industry. A monolayer of specifically designed Ag nanoparticles was employed in a recent work to increase the sensitivity for Raman detection and facilitate the identification of the concentration of methyl parathion [39].

 The governments of several industrialised nations continue to spend a lot of money on cutting-edge research and development of nanotechnology in a variety of fields, including the food and agriculture industries. It is clear that nanotechnology has played a significant role in improving the economic standing of nations like the United States, China, Germany, Russia, and Japan. Other nations, including Taiwan and India, are attempting to raise their annual expenditures for cutting-edge nanotechnology research and development in order to improve their competitiveness in the global market and to meet the needs of the economic environment [40]. Applications of nanosensors for agricultural product safety are listed in Table 1.

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

 Metallic nanoparticles offer a wide range of uses in the field of food technology due to their unique shape- and size-dependent characteristics. Metallic nanoparticles are exceptional for use in combination with enzymes, medicines, ligands, antibodies, colorimetric and fluorometric agents, and other types of biomolecules due to their optical, chemical, mechanical, antibacterial, and electronic capabilities [46].These nanoparticles can therefore be used for a variety of tasks, including advanced diagnostic assays, radiation, thermal ablation, gene and medication delivery, optical imaging, efficient antibacterial activity, and cleanup of hazardous substances [47, 48]. Metallic nanoparticles also have a significant impact on the production, consumption, and ability to immediately respond to pathogens, packaging problems, pesticides, and hazardous residues by detecting microbial deterioration of the quality of food as well as pollutants.

 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. In nanosensors or nanobiosensors, the combination and aggregation of Au nanoparticles is predicted to dramatically increase the sensitivity of local surface plasmon resonance (SPR) by a factor of two to ten, as well as surface-enhanced Raman scattering by a factor of 106 to 109 [49]. The observed properties of Au nanoparticles include strong local SPR absorption, along with extremely high elimination coefficients in the visible wavelength range, and it typically exhibits a colour change from deep red to blue after reaching the aggregation stage [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 mycotoxin produced by the Aspergillus and Penicillium types of agricultural and food toxins or pollutants, is detected using Au nanoparticle SPR. For the purpose of detecting the ochratoxin-A toxin, thiolated aptamers are covalently linked to Au nanoparticles via an Au-S (gold-sulfur) connection [52]. One of the main spectroscopic detecting methods, with regard to quick response and better biocompatibility, has been demonstrated to be the ability of the antioxidants to protect the fluorescence of Au nanoparticles. This methodology is used for evaluating the antioxidant quantity in commercially used and consumed fruit juices [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 cutting-edge packaging technologies that guarantee the quality and safety of the food. One excellent illustration of the part nanotechnology is already playing in food sector packaging is the application of an aluminium nanolayer over food packaging. 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 analytical methods mostly include measuring changes in mass resonance frequency using a cantilever, functionalized plasmonic nanoparticles, or gold and silver nanoparticles infused with DNA to measure changes in optical characteristics [Table-1].

|  |
| --- |
| **Table 1 - Different types of nanobiosensors used in agriculture and Food Industry**  |
| **Nanobiosensors** | **Type of Nanomaterial** | **Applications** | **Reference** |
| fluorescent-based nanosensor | Quantum dots | Pathogen Detection | [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 have found applications in the agricultural and food industries. They can be used singly or in combination with packaging as nano tracers to track the history of food products and determine whether they are still within acceptable quality limits at any given time. Examples include the use of nanosensors or nanobiosensors in food packaging to detect microbe growth and colour changes as an edge level is approached. In the near future, nanosensors used in conjunction with process control to monitor storage conditions will be helpful to stop food poisoning [22, 62]. In the agricultural industry, nanotechnology has been shown to increase productivity, enhance soil quality, promote plant growth, and provide effective monitoring system, for monitoring of storage conditions, will be helpful in the near future to prevent food poisoning [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 areas, the use of nanosensors can support the approach as well as enable the application of various analytes to be explored, starting with the macro food and moving on to proteins, carbohydrates, lipids, dyes, pigments, or preservatives.

We anticipate that the creation of novel nanosensors, as emphasised in this chapter, will improve the production of accessible and cost-effective nanomaterial-based sensing systems. However, the full potential of nanobiosensors in the food and agricultural industries has not yet been achieved. This chapter primarily covered numerous elements and uses for nanobiosensors that are in use in the diverse fields of agriculture and food.

 **VI. References**

1. T.V. Duncan, “Applications of nanotechnology in food packaging and food safety: barrier materials, antimicrobials and sensors” *J. Colloid Interface Sci*. vol 363, No 1, p.1, Nov.2011

2. J. Potocnik, Commission recommendation of 18 October 2011 on the definition of nanomaterial. *Off. J. Eur. Communities Legis*, vol *275*, p.38, Oct. 2011

1. S. Sahani & Y. C. Sharma Advancements in applications of nanotechnology in global food industry. *Food Chemistry*, vol *342*, p. 128318, Apr. 2021.
2. M. Naghdi, M. Taheran, R. Pulicharla, et al “Pine-wood derived nanobiochar for removal of carbamazepine from aqueous media: Adsorption behavior and influential parameters”. *Arabian Journal of Chemistry*, vol *12 No.*8, p. 5292 Dec. 2019.
3. A. Gupta, H.B. Eral, T.A. Hatton, P.S. Doyle “Nano emulsions: formation, properties and applications” *Soft matter*, vol *12* No.11, p. 2826 Dec 2016
4. J. Jeevanandam, A. Barhoum, Y.S. Chan, A. Dufresne, M.K. Danquah (2018). “Review on nanoparticles and nanostructured materials: history, sources, toxicity and regulations” *Beilstein journal of nanotechnology*, vol. *9* no.1, p. 1050, Apr. 2018
5. M.A. Cerqueira, A.A. Vicente, L.M. Pastrana “Nanotechnology in food packaging: opportunities and challenges” *Nanomaterials for food packaging*, Vol 1, p. 1, Jan. 2018.
6. H. Gleiter “Nanostructured materials: basic concepts and microstructure” *Acta materialia*, Vol *48, No.*1, p 1, Jan 2000.
7. M. Thiruvengadam, G. Rajkumar, I.M. Chung. “Nanotechnology: current uses and future applications in the food industry”. *Biotech*, Vol *8*, p. 1, Jan 2018.
8. V. Devra, “Applications of Metal Nanoparticles in the Agri-Food sector”. *Egyptian Journal of Agricultural Research*, Vol*100, No.*2, p.163, July 2022.
9. Y.A. Selim, M. A. Azb, I. Ragab and M. HM Abd El-Azim “Green synthesis of zinc oxide nanoparticles using aqueous extract of Deverra tortuosa and their cytotoxic activities”. *Scientific reports*, *10*(1), p. 3445, Feb 2020.
10. N. Nagar, and V. Devra. “Activation of peroxodisulfate and peroxomonosulfate by green synthesized copper nanoparticles for Methyl Orange degradation: a kinetic study”. *Journal of environmental chemical engineering*, Vol*5, No.*6, p.5793, Dec 2017.
11. S. S Ali, R.Al-Tohamy, E.Koutra, M. S Moawad, Kornaros,A. M Mustafa., ... & J.Sun, “Nanobiotechnological advancements in agriculture and food industry: Applications, nanotoxicity, and future perspectives” *Science of the Total Environment*, Vol *792*, p. 148359, Oct. 2021.
12. A.Rawat, R.Kumar, B. Bhatt., & P. Ram, “Nanotechnology in agriculture-a review”. *Int J Curr Microbiol App Sci*, vol *7*, No.8, p. 969, 2018
13. E. Parthiban, N. Manivannan,R. Ramanibai, &N. Mathivanan “Green synthesis of silver-nanoparticles from Annona reticulata leaves aqueous extract and its mosquito larvicidal and anti-microbial activity on human pathogens”. *Biotechnology Reports*, Vol. *21*, p.e00297 , March 2019.
14. A.A. Malandrakis, N. Kavroulakis & C.V. Chrysikopoulos “Use of copper, silver and zinc nanoparticles against foliar and soil-borne plant pathogens”. *Science of the total environment*, Vol. *670*, p.292, June2019
15. A. Kaphle, P. N Navya, A.Umapathi, & H.K.Daima “ Nanomaterials for agriculture, food and environment: applications, toxicity and regulation” *Environmental chemistry letters*, vol *16 No.*1, 43, March 2018.
16. X. He, H. Deng, H. Hwang “The current application of nanotechnology in food and agriculture” *Journal of food and drug analysis*, Vol *27, No.* 1, p.1 Jan 2019.
17. M. Pereda, N.E. Marcovich, M.R. Ansorena). Nanotechnology in food packaging applications: barrier materials, antimicrobial agents, sensors, and safety assessment. p. 2035, Jan 2017
18. S. Neethirajan,V. Ragavan,X. Weng and R.Chand “Biosensors for sustainable food engineering: challenges and perspectives”. *Biosensors*, Vol *8,* No.1, p.23, March 2018.
19. R. L.Chopade,P.P. Pandit,V. Nagar,V. Aseri, B. Mavry,A. Sharma,A. Singh,R.K. Verma,G. Awasthi, K.K. Awasthi, and M.S. Sankhla. “Carbon nanotube-based nano-biosensors for detecting heavy metals in the aquatic environment”. *Environmental Science and Pollution Research*, Vol *30, No.*5, p.11199, Jan 2023.
20. L.Marchiol.” Nanotechnology in agriculture: new opportunities and perspectives”. *New Visions Plant Sci*, Vol *9 No.*4, p.161, Sept.2018.
21. M.Thakur, B.Wang, and M.L.Verma. “Development and applications of nanobiosensors for sustainable agricultural and food industries: Recent developments, challenges and perspectives”. *Environmental Technology & Innovation*, Vol *26*, p.102371, May 2022.
22. A.C.Oluwaseun, P. Phazang and N.B. Sarin ”Biosensors: a fast-growing technology for pathogen detection in agriculture and food sector”. *Biosensing technologies for the detection of pathogens-a prospective way for rapid analysis, 1st edn. INTECH*, pp.37-52, March 2018.
23. K.Girigoswami and N. Akhtar “Nanobiosensors and fluorescence-based biosensors: An overview”. *International Journal of Nano Dimension*, Vol*10, No.*, p.1, Jan 2019.
24. S.P.K.Malhotra and T.Mandal “Zinc oxide nanostructure and its application as agricultural and industrial material”. *Contamin. Agric. Environ. Health Risks Remed*, Vol *1*, p.216 June 2019.
25. G.P. Nikoleli, D.P.Nikolelis,C.G. Siontorou,M.T. Nikolelis and S. Karapetis, “The application of lipid membranes in biosensing”. *Membranes*, Vol *8 No.*4, p.108, Nov. 2018.
26. R.Reshmy,E. Philip, S.A. Paul, A. Madhavan, R. Sindhu, P. Binod, A. Pandey and R.Sirohi, “Nanocellulose-based products for sustainable applications-recent trends and possibilities”. *Reviews in Environmental Science and Bio/Technology*, Vol. *19*, p.779, Dec 2020.

29. A.Z.M. Badruddoza, Z.B.Z. Shawon, W.J.D. Tay, K. Hidajat, M.S. Uddin, “Fe3O4/cyclodextrin polymer

nanocomposites for selective heavy metals removal from industrial wastewater”, *Carbohydr. Polym*. Vol.91 (2013)p. 322, Jan. 2013.

30. P. Shukla, P. Chaurasia, K. Younis, O.S. Qadri, S.A. Faridi, G. Srivastava, “Nanotechnology in sustainable

agriculture: studies from seed priming to post-harvest management “.*Nanotechnol. Environ. Eng.*Vol 4 , p. 1, Dec.2019

31. M.E. Hoque, A.M. Peiris, S.M. Atiqure Rahman, M. Abdul Wahab, “New generation antibacterial nanofibrous membrane for potential water filtration”, *Curr. Anal. Chem.* Vol 14, No. 3, p. 278, June 2018.

32. P.Bairwa,N. Kumar, V.Devra, V. and K.A. Abd-Elsalam, “Nano-Biofertilizers Synthesis and Applications in Agroecosystems”. *Agrochemicals*, Vol *2, No.*1, p.118, Feb 2023.

33. A. Dubey, D.R. Mailapalli, “Nanofertilisers, nanopesticides, nanosensors of pest and nanotoxicity in

agriculture, in: *Sustainable Agriculture Reviews*, Springer, Vol 19, p. 307, 2019.

34. N. Scott, H. Chen, “Nanoscale science and engineering for agriculture and food systems”, Ind. Biotechnol.

Vol. 8, No. 6, p.340, Dec.2012

35. S. Singh, A. Srivastava, H.-M. Oh, C.-Y. Ahn, G.-G. Choi, R.K. Asthana, “Recent trends in development of

biosensors for detection of microcystin” *Toxicon* Vol 60, No. 5, P. 878, Oct.2012

36. Z. Wang, F. Wei, S.-Y. Liu, Q. Xu, J.-Y. Huang, X.-Y. Dong, J.-H. Yu, Q. Yang, Y.-D. Zhao, H. Chen,

“Electrocatalytic oxidation of phytohormone salicylic acid at copper nanoparticles-modified gold electrode

and its detection in oilseed rape infected with fungal pathogen Sclerotinia sclerotiorum”. *Talanta Vol* 80. No.3,

P. 1277, Jan 2010.

37. H. Li, C. Xie, S. Li, K. Xu, “Electropolymerized molecular imprinting on gold nanoparticle-carbon nanotube

modified electrode for electrochemical detection of triazophos”, *Colloids Surf. B: Bioint*erfaces Vol.89

P. 175, Jan. 2012

38. C. Chen, Z. Yuan, H.-T. Chang, F. Lu, Z. Li, C. Lu, “Silver nanoclusters as fluorescent nanosensors for selective

and sensitive nitrite detection”, *Anal. Methods* Vol. 8, No. 12, p. 2628, 2016

39. L. Zhang, “Self-assembly Ag nanoparticle monolayer film as SERS substrate for pesticide detection” *Appl. Surf. Sci*. Vol. 270, No.1, P. 292, Apr.2013

.

40. M.C. Roco,”The long view of nanotechnology development: the National Nanotechnology Initiative at 10 years” *Journal of Nanoparticle Research*, Vol*13*, P.427, Feb 2011.

41.S.Sargazi, I.Fatima, M.H.Kiani, V. Mohammadzadeh, R. Arshad, M. Bilal, A. Rahdar, A.M.Díez-Pascual and R. Behzadmehr,”Fluorescent-based nanosensors for selective detection of a wide range of biological macromolecules: A comprehensive review”. *International Journal of Biological Macromolecules*, Vol 206, p.115, May 2022.

42. A. Antonacci, F. Arduini, D Moscone, G. Palleschi and V.Scognamiglio. “Nanostructured (Bio) sensors for smart agriculture”. *TrAC Trends in Analytical Chemistry*, Vol *98*, p.95, Jan 2018.

43. Y.Xu, Y.Dhaouadi, P. Stoodley, and D.Ren. “Sensing the unreachable: challenges and opportunities in biofilm detection”. *Current opinion in biotechnology*, Vol *64*, p.79, Aug. 2020.

44. J.C. Negrete, “Nanotechnology an option in Mexican agriculture”. *Journal of Biotechnology & Bioinformatics Research*, Vol *2 No*. 2, p.1, 2020.

45. A.James, F. Franco, E.M. Merca, S. Rodriguez,F. Johny, P. Balidon-Veronica, M. Divina,A. Evangelyn, C. Alocilja, and L.M. Fernando. “DNA based electrochemical nanobiosensor for the detection of Phytophthora palmivora causing black pod rot in cacao (Theobroma cacao L.) pods”. *Physiol. Mol. Plant Pathol*, Vol *107*, p.14, 2019.

46. K.A. Abd-Elsalam, ed. “*Fungal Cell Factories for Sustainable Nanomaterials Productions and Agricultural Applications”*. Elsevier, Oct 2022.

47. D. MubarakAli, H. Kim, P. S. Venkatesh, J. W.Kim & S. Y. Lee “ A systemic review on the synthesis, characterization, and applications of palladium nanoparticles in biomedicine”. *Applied Biochemistry and Biotechnology*, p.1, March 2022.

48. A. A. Yaqoob, H.Ahmad, T. A.Ismail,& Mohamad Ibrahim, M. N. (2020). “Recent advances in metal decorated nanomaterials and their various biological applications: A review”. *Frontiers in chemistry*, Vol *8*, p.341,may 2020.

49. J.K.Patra, G.Das, L.F Fraceto, E.V.R. Campos,M.D.P Rodriguez-Torres, L.S.Acosta-Torres ,L.A. Diaz-Torres,R. Grillo,M.K. Swamy, S. Sharma and S. Habtemariam, 2018. Nano based drug delivery systems: recent developments and future prospects. *Journal of nanobiotechnology*, Vol*16, No.*1, p.1, Dec 2018.

50. Z.B.Z. Shawon, M.E. Hoque &S.R. Chowdhury. “Nanosensors and nanobiosensors: Agricultural and food technology aspects”. In *Nanofabrication for smart nanosensor applications*, p.135 Elsevier, Jan 2020.

51.. N.Shreyash,S. Bajpai, M.A. Khan, Y.Vijay, S.K.Tiwary, and M. Sonker,. “Green synthesis of nanoparticles and their biomedical applications: a review”. *ACS Applied Nano Materials*, Vol *4 No.* 11, p11428, Oct. 2021.

52.. X. Wei, M.Yin, L. Zhang, H. Lin,J. Wang,W. Xie and D. Xu “Surface Plasmon Resonance (SPR) biosensor for detection of mycotoxins: A review”. *Journal of Immunological Methods*, p.113349 Sept. 2022.

53. H.Kumar, K.Bhardwaj, E.Nepovimova, K. Kuča, , S. D.Singh Dhanjal, S.Bhardwaj, S.K. Bhatia, R. Verma & D. Kumar “Antioxidant functionalized nanoparticles: A combat against oxidative stress”. *Nanomaterials*, Vol*10 No* 7, 1334, July 2020.

54. F. A. Dar, G.Qazi & , T. B.Pirzadah “Nano-biosensors: NextGen diagnostic tools in agriculture”. *Nanobiotechnology in Agriculture: An Approach Towards Sustainability*, p.129, 2020

55. A.Fonseca-García, E. J.Jiménez-Regalado, & R. Y. Aguirre-Loredo. “Preparation of a novel biodegradable packaging film based on corn starch-chitosan and poloxamers” *Carbohydrate Polymers*, Vol *251*, p.117009, Jan 2021

56. S.H.Jung, H.T.Lee, M.J.Park, B. Lim, B.C.Park, Y.J.Jung , H.Kong, D. H. Hwang, H.I.Lee. and J.M.Park, “Precisely tunable humidity color indicator based on photonic polymer films”. *Macromolecules*, Vol *54, No.* 2, p.621, Jan 2021.

57. L.A.Pola-López, J.L. Camas-Anzueto, A. Martínez-Antonio,M.C. Luján-Hidalgo,G. Anzueto-Sánchez, V.M.Ruíz-Valdiviezo,R. Grajales-Coutiño and J.C. Gonzalez. “Novel arsenic biosensor “POLA” obtained by a genetically modified E. coli bioreporter cell”. *Sensors and Actuators B: Chemical*, Vol *254*, p1061, Jan 2018.

58. L.Ga, J. Ai and Y. Wang, “AS1411-templated fluorescent Cu Nanomaterial’s synthesis and its application to detecting melamine”. *Journal of Chemistry* vol 2020, p.1, May 2020.

59. J.M.Moon, N. Thapliyal, K.K. Hussain, R.N. Goyal and Y.B. Shim. “Conducting polymer-based electrochemical biosensors for neurotransmitters: A review”. *Biosensors and Bioelectronics*,Vol *102*, pp.540, Apr 2018.

60. R. Meraat, K.Issazadeh, A. Abdolahzadeh Ziabari and M. Faezi Ghasemi. “Rapid detection of Escherichia coli by β-galactosidase biosensor based on ZnO NPs and MWCNTs: a comparative study”. *Current Microbiology*, Vol *77*, p.2633, Oct. 2020.

61.F. Huang, R. Guo, L. Xue, G. Cai, G, S. Wang,Y. Li, M. Liao, M.Wang, J. and J. Lin. “An acid-responsive microfluidic salmonella biosensor using curcumin as signal reporter and ZnO-capped mesoporous silica nanoparticles for signal amplification”. *Sensors and Actuators B: Chemical*, Vol *312*, p.127958, June 2020.