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Nano-Biosensors: Applications in Agriculture and Allied Fields

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Abstract

Nano-biosensor is the modified version of biosensor which uses nanomaterials *i.e.*, nanoparticles and nanostructures. Because of unique physicochemical properties of nanomaterials, nano-biosensor is highly selective, sensitive, stable, and accurate and can be used for in-situ real time monitoring for need-driven purposes. This technology enables us to detect the pesticides, metals, toxins and plant metabolites at a very low concentration. Nano-based sensor technology has a lot of scope in sustainable agriculture because it may help to monitor and develop smart delivery system for fertilizer and plant protection chemicals which releases the inputs in a controlled manner. This technology can also be used in livestock and fisheries sector for real time quality and safety monitoring. However, their use is still confined at laboratory and research level. So, policy intervention is required for their mass recommendation at field level and commercial utilization.

Introduction

To feed the gigantic population, India has been engaged in the herculean task of increase the agriculture production up to a satisfactory level, and achieved it to some extent. To enhance the agricultural productivity, farmers are already depending on high-input fertilizers and pesticides. However, there are several factors which hamper the agricultural productivity like nutrient deficiency, water scarcity, depletion of land and water resources, climate change and rapid industrialization. Practice of high-input agriculture and industrialization surrounding the farm fields have caused different degrees of pollution of heavy metals and pesticides in environment matrix like soil, water and food. On the other hand, due to constant depletion of arable land and fresh water resources, there is a need for sustainable agriculture which involves precise and balanced use of agricultural input without any harmful effect on environment. At the same time, detection of pollution and contamination arises due to overuse of pesticides and metals in the environment is also important from human and environment health perspective.

All these challenges can be overcome by using an emerging technology, called nano-biosensor. Nano-biosensors are the modern and modified version of biosensor which is a compact analytical devise or biologically derived sensitized element linked to a physico-chemical transducer. By early prediction of natural resources (land and water), nutrient availability, pest and disease conditions, nano-biosensors can help to increase the agricultural production in sustainable manner using precise input without compromising the quality of food. It may directly help in detecting the contaminants like pesticide residues and traces of heavy metals in food and environment. Sensor-based technology is also potential to monitor animal and fish health as well as for quality check of animal and fish products. In total, appropriate and regulated

use of this technology can boost up agricultural and allied sectors' productivity and can be proven beneficial with apt use (Figure 1).

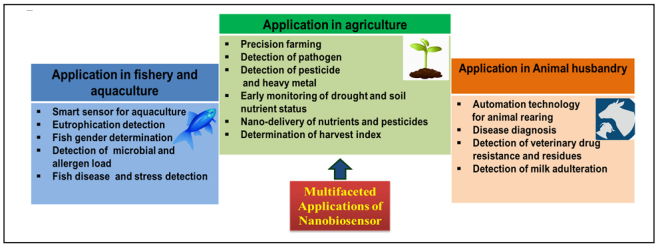

Figure 1: Application of nano-biosensor in agriculture and allied sectors

Composition and Mode of Function of Nano-Biosensor

A classical nano-biosensor is composed of three components *i.e*., (a) biological sensitive probe element, (b) transducer, (c) data recorder and displayer. Biological probe are sensing element which interact with target analytes, and further determine the signal which is proportional to the concentration of analyte. Different biological elements like enzymes, antibodies, DNA/RNA, microorganisms and organelles are used as nano-biosensor which received the signal from the interest analytes and transmits properly to the transducer. A schematic diagram is shown to depict the basic principle of nano-biosensor (Figure 2). In general, biosensor consists of receptor and transducer in micro or macro-size; however, in nano-biosensor one of these should be in nanosize. Transducer is a physical element which converting the recognition signal events into a digital signal and based on the transduction element, the sensor can be categorized as electrochemical, optical, mass sensitive, piezoelectric or thermal *etc*. This sensor-based technology has several advantages like:

- Accurate in early warning.
- They are highly selective towards the target analytes due to their high surface to volume ratio.
- Very accurate for in-situ real time monitoring.
- Portable.
- Reduce the cost and time of analysis as it eliminates the step of collection, packaging and transportation of sample.
- Highly stable in nature.
- Helps in multi-analyte analysis.

Nano-Biosensor for Precision and Sustainable Agriculture

Maximizing the crop yield with minimum or optimum delivery of input is the main aim of precision farming. Integration of nano-based biosensor technology with global positioning system (GPS) and satellite imaging of fields, farm manager can remotely monitor the soil humidity, temperature and nutrient status, level of pest and disease infestation, requirement of fertilizer and irrigation. Based on the recorded parameters by nanosensor on regular basis, need-based decisions can be taken for optimum scheduling of fertilizer and irrigation as well as appropriate application of pesticides. This will reduce the excess application of fertilizer and pesticides, both in terms of use and money.

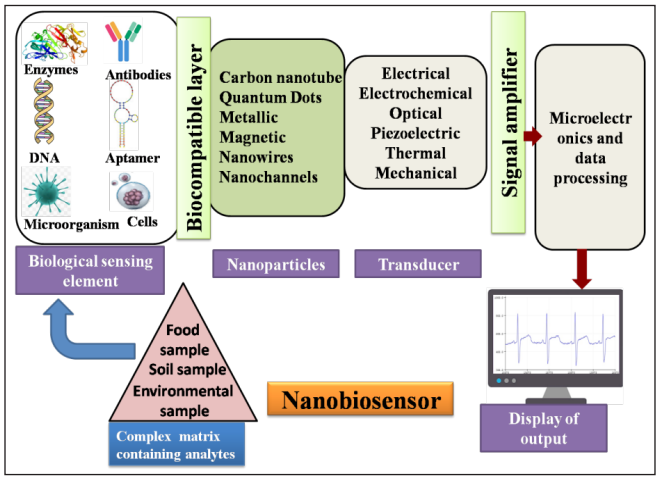

Figure 2: Schematic diagram for nano-biosensor development and its application

Nano-based sensor technology may help to monitor and develop smart delivery system for fertilizer and plant protection chemicals which releases the inputs in a controlled manner. A gold nanoparticle was found to be efficient in detection of urea and urease enzymes activity in soil. Biochemical properties like contents of total phenolic, ascorbic acid in horticultural crop indicate the crop maturity. Nano-based sensor technology can be used to monitor these properties and thus may help to take the decision on harvesting time. This will help to develop harvest index of crop and also to enhance the post-harvest quality and shelf life. Electronic nose (E-Nose) technology can be employed to identify the quality deterioration of seed during storage. This can be achieved by sensing the volatile aldehyde released from the seed due to aging process and thus it may help to isolate the fresh seeds from the spoiled ones.

Nano-Biosensor as a Diagnostic Tool for Disease Assessment

Frequent occurrence of diseases is the major limiting factors for crop production. Early prediction of plant diseases may help to develop a comprehensive and effective plant pest and disease management strategy. Nanostructured (bio) sensors can be effectively used for early diagnosis of plant diseases in a superior manner as

compared to conventional techniques in terms of sensitivity, accuracy, saving of cost, and non-destructive sampling. New advance technologies like antibody conjugated fluorescent silica nanoparticles, quantum dot (QD)-based fluorescence resonance energy transfer (FRET) nano-biosensor, nanorod-based fiber optic particles, plasmon resonance immunosensor have helped for high throughput analysis for pathogen detection with higher sensitivity and specificity. Plant synthesized several volatile compounds during the infection and thus identifying the disease specific volatile compounds my help in early diagnosis of the diseases before the formation of any visible symptoms and thus control measures can be taken at initial stage. An aperometric biosensor based on bi-enzyme modified electrode based was developed to detect methyl salicylate, a volatile compounds released in pathogen infected plants (Fang *et al*., 2016).

Nano-Biosensor for Detection of Nutrient and Metal Pollution in Soil and Plant

Several heavy metals like arsenic, mercury, cadmium, lead *etc*. are present in the soil and water environment and crops may accumulate these metals in final harvested products or grains if they are cultivated in those environment. This may cause a serious threat to plant and finally human population. So, detection of heavy metals in both soil and plants is crucial from human health perspective. Though sophisticated technology like AAS, ICP-MS have a lot of limitations like high operation cost, expertise in handling, labour-intensive, tedious sample preparation and time-consuming. Over and above, they are not suitable for rapid on-the-spot analysis. Nano-biosensor can be a promising tool for field-based heavy metal detection in future which is not possible by present sophisticated instruments.

Several precision nano-device like FRET, quantum dots and cantilever biosensor were developed to detect heavy metals. Nano-biosensor may also help to detect the phytotoxicity of heavy metal ions in plant by measuring the changes in plant water status, chlorophyll content *etc*. due to metal contamination. Macronutrients like nitrogen and phosphorus are crucial for plant growth. However, their excessive use results in nitrate-N and phosphate-P contamination in soil and water; hence, detection of them is crucial. Hence, nanosheets and nanofibers based electrochemical sensor was developed for accurate detection of nitrate-N in real-field soil samples.

Pesticide Detection in Food and Environment Matrix by Nano-Biosensor

In order to reduce the loss in agricultural productivity; use of pesticides is inevitable for modern crop management. However, their widespread use has resulted in their accumulation in environment and food matrix and ultimately affecting the human and animal health. Ensuring food and environment safety, development of superior pesticide detection technique at low concentration level is pre-requisite for human health and safety point of view. Present conventional methods for detecting the pesticides like liquid/gas chromatography and mass spectrometry approach is costly, time-consuming, labourious, tedious sample preparation methods and required professional operators and are not suitable for on-site real time detection. Nano-biosensors can help to overcome these constrains. Based on the principle of inhibition of enzyme acetylcholinesterase (AChE) activity, several nano-biosensor has been developed to detect organophosphorus and carbamate pesticides (Table 1). AChE is acholinergic enzyme primarily found at postsynaptic neuromuscular junctions and it breaks down the neurotransmitter acetylcholine and thus it stabilizes it. Present of trace amount of these pesticides resulted in inhibition of AChE esterase activity. Similarly, flouroimmuno assay based nano-biosensor by utilizing cadmium telluride quantum dot nanoparticle (CdTe QD) had detected the herbicide 2,4-D. Presently research is undergoing for development of nano-biosensor for detection of multi-pesticides.

Table 1: Types and applications by nanobiosensor

Nanobiosensor	Type of biological entity	Nano-materials	Pesticide	Detection limit	References
1. Enzymatic	Acetylcholin esterase	Transition metal carbides nanosheets and chitosan	Malathion	0.3×10^{-14} M	Zhou *et al*. (2017)
2. Colorimetric	Aptamer	Gold nanoparticles	Acetamiprid	5 nM	Shi *et al*. (2013)
3. Enzymatic	Tyrosinase-modified screen-printed carbon electrodes	ZnO nanoparticles	Chlortoluron	0.02 µM	Haddaoui and Raouafi (2015)
4. Optical	Acetylcholinesterase enzyme	Cd-Te semiconductor quantum dots	Paraoxon and parathion	1.05×10^{-11} M (Paraoxon) and 4.47×10^{-12} M (Parathion)	Zheng *et al*. (2011)

Applications in Fisheries, Aquaculture and Animal Husbandry

Fish is an important source of protein and their demand and consumption as a protein requirement is increasing day by day. The aquaculture activities hence are also increasing. However, rearing aquatic lives in traditional process requires more labour, time and skilled operators. With the help of sensor-based technology this operation can even be done with unskilled persons. Nanosensors such as "Smart fish" which can remotely monitor the fish health and their geographical location and they may be very useful for application in cognitive cage culture.

Gender-specific life processes in fish can be determined by using nano-biosensor like electrochemical DNA biosensor. Due to highly perishable in nature, spoilage due to microbial contamination in fishes is regular phenomenon. For this, malpractice like use of preservatives like formalin is common to preserve the fishes. But due to carcinogenic in nature, formalin detection in fishes at low level is very much important. By using CdS nanoparticles as a nano-interface, a non-enzymatic electrochemical biosensor was developed for real-time detection of formalin in fish samples. Several sensor-based technology has also been developed to determine fish allergens like histamine and parvalbumin. Carbon nanotube based biosensor was used for detection of blood glucose level in fish and can be effectively used for stress monitoring in free-swimming fish.

Nano-based biosensor technology can be used to diagnose the animal diseases. For ultrasensitive diagnosis of foot and mouth disease, gold nanoparticle based nanosensor was employed. Veterinary drugs are widely used in animal husbandry and their residues in food need to be monitored for ensuring food safety. Fluorescent nanomaterials based sensors are found to be attractive for detection of veterinary drug residues. Nowadays several sensor-based technologies are also used for regular health monitoring of animal for record keeping.

Conclusion

Now-a-days, application of nanotechnology based biosensors is sensibly increasing, due to its cost-effectiveness, sensitive and rapid measurement. Further, there is a lot of scope to increase its sensitivity and specificity; and also the feasibility of its applications in real field situation needs to be checked. On the other hand, their use is still confined at laboratory and research level, so their commercial utilization is not fully explored. Government intervention is required to decentralize technology to the farmers which may help to increase the market demand. Use of engineered nano-materials has also raised the question of their safety issues in terms of both environment and human health. Moreover, their potential use in complex matrix like soil and plant has to be explored more. Insufficient knowledge is available with reference to their toxicity, bioaccumulation and associated exposure risk.

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