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Nanotechnological interventions in sustainable agriculture

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The major problems associated with agriculture are the sustainable management of natural resources. With technological innovations and capital investments crop production has increased but care of ecological systems has not been given priorities and thus created imbalance in the natural cycle of the soil, crop productivity, salinization, moisture content, organic matter and seeping problems of pesticides. Nanotechnology provides a plethora of techniques to face the challenges of increasing population and food production, at the same time taking care of the environment, and has opened new avenues for sustainable agriculture. It has a myriad of applications, whether it is in medicine, electronics, agriculture, food technology, environment, cosmetics. Worldwide, there is improvement in sensing which is highly important in agriculture. Crop yield mainly depends on soil fertility, water supply and other environmental factors. Nanotechnology has revolutionised food production commonly referred to as "*green nanoagroscience*" which implements green chemistry in an eco-friendly manner and using biocompatible methods, which is cost-effective. This review mainly focuses on the latest development in nanobiotechnology and their applications along with challenges in sustainable agriculture developmentand the future prospects.

Keywords: Engineered nanoagroparticles, Green nanoagroscience, Nanosensors, Sustainable agriculture

Introduction

Nanotechnology deals with systems made of nanoparticles having size between 1 to 100 nm. In these dimensions not only quantum effects but also the statistical effects are important in determining them. On 26th December 1959, R.P. Feynman at Caltech gave a talk entitled "There is plenty of room at the bottom" and conveyed the idea and possibility of utilisation of nanotechnology[1]. In 1974 professor Norio Taniguchi coined the term "nanotechnology"[2]. However, remarkable development happened when scanning tunnelling and atomic force microscopy were developed. Nanoparticles such as gold nanoparticles that can be used in biosensing in medicine, nanosensor to measure abiotic componentsin fields, carbon nanotubes are used to make strong materials and in environmental clean-up[3]. In many aspects their properties are different from bulk matter such as colour change depending on the size of particle due to surface plasmon resonance, increased reactivity, conversion of ferromagnetism to paramagnetism, decreased melting point viscosity etc. these properties result in special properties of nanoparticles which make them useful for making ultrasensitive sensors useful in medicine, electronics, agriculture, food technology, environment, cosmetics, and so on[4].

Human civilization started agriculture about 10,000 BC since then there has been a lot of development in agriculture practices, *viz*. fertilisers, pesticides and using disease resistant varieties. To meet the population demand there was shift to monoculture cropping system which is highly dependent on excessive use of insecticides and pesticides causing a grieving situation in the agriculture sector. The excessive use of these chemicals has resulted in salinity of soil, loss of soil fertility, pesticide poisoning and many other repercussions. Twenty six million people become victims of pesticide poisoning annually on a global basis which results in about 220,000 annual deaths[5]. Globalisation has resulted in the awareness and ultimately resulting in shifting of agrotechnology towards greener technology systems. After successful application of nanotechnology in improving human health the agriculture scientist used this technology to attain a sustainable agriculture system. Fertilisers or pesticides coated with nanoparticles and attractants improve their efficiency as nanoparticle cages prevent release of pesticide or fertiliser until the particle reaches to its desired destination *viz*., insects or roots, respectively. Nanotechnology can also help in predictions through

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nanosensors together with artificial intelligence and cloud computing to revolutionise farming by efficient management of resources. In addition, nanotechnology is capable of reducing waste and at the same time helps to reuse waste.

Application of nanotechnology in agriculture

Agricultural yield depends strongly on the environmental factors and other biotic stresses. Thereby measuring the soil fertility and moisture level are very important to ensure that crops will get the right nutrition. In the past, various methods were available for monitoring agricultural ecosystems such as GC, HPLC and MS *etc*. with these techniques detection and quantification of contaminants becomes easy but they are time consuming, costly, and require a set of sophisticated appliances along with skilled personnel. Nanotechnology methods were developed and tested as potential to improve the crop productivity using nanosensor, nanoagroparticles containing bactericides, fungicides and feritilizers. In addition to increase the crop productivity these nanoparticles perform other functions like controlled release of nutrients, sensing abiotic and biotic stresses, minimize the release of chemicals into environment.

Nanosensors

Nanosensors are nanodevices capable of detecting change in abiotic and biotic components in the environment. Depending on the structure and application different types of nanosensor have been devised with enormous speed, selectivity and sensitivity as compared to traditional methods. Nanosensors are the most emerging and promising tool for sustainable agriculture. They can be used to check contamination and moisture in soil as well as changes in the environmental conditions (Table 1).

Nanoagroparticles

Nanoagroparticles are nano-sized particles used to tackle the problems faced by agriculture sector. The use of nanoagroparticles can also potentially aid in mitigating the environmental issues associated with currently used chemical fertilisers and pesticides in conventional modern agriculture[6,7]. Engineered nanoagroparticles are a novel technological innovation projected to boost the performance of agricultural systems. Nanotechnological interventions may aid in addressing agricultural challenges like biotic and abiotic stresses (pollution and nutrient deficiency), thereby facilitating productivity. Nanoagroparticles that have led to the sustainable agricultural systems include nanofertilizers, nanopesticides, nanoweedicides, and nanosensors (Table 2).

Nano fertiliser: Traditionally manure was used in fields made organically from organic waste usually by vermicomposting. Later on chemical based fertilisers came into play, rich in NPK most needed macronutrients. The focus shifts towards biofertilizers which are substances having a mixture of microbes which improve bioavailability of nutrients and thereby improving plant growth. These microbes will colonise the rhizosphere[8]. Biofertilizers are cheaper and more eco - friendly. For example cyanobacteria, PSB, VAM, and other micronutrient solubilising bacteria. Nano fertilisers are nanoparticle encapsulated biofertilizers. These are even more

Table 1 —Different Nanosensors used to detect bacterial and viral pathogens

Type of pathogen	Type of Nanosensor	Pathogen detected
Bacterial	silica nanoparticles	*Xanthomonasaxonopodisp v. Vesicatoria*[27]
Bacterial	Cu nanoparticle-modified gold electrode	*Sclerotinia sclerotiorum*[28]
Fungal	TiO_2 or SnO nanoparticles	*Phytophthora cactorum*[29]
Fungal	Quantum dots fret-based biosensor	*Candidatusphytoplasma aurantifolia*[30]
Viral	Carbon nanotube-based Cu nanoparticles	*Begomovirus*[31]
Viral	Chemiresistive sensor	*Cucumber MV*[32]
Viral	Nanorod-based fibre-optic particleplasmon resonance immunosensor	*Cymbidium MV and Odontoglossum RSV*[33]
Viral	Nanowire-based biosensor	*Cucumber MV and Papaya RSV*[34]

Table 2 —Different types Nanosensors used to detect pesticides

Type of Nanosensor	Pesticides
electrochemical magneto immunosensing	Atrazine[35]
Core-shell nanosensors	
Nanocomposite ZrO_2/gold film electrode	Parathion[36]
Amperometric biosensor	Organophosphates[37]
MnO_2 nanosheet carbon dots	organophosphorus pesticides[38]
CdTe as fluorescent probe Based optical biosensor	
ZnO quantum dots	aldrin, tetradifon, glyphosate, and atrazine in water[39]
fluorescence sensor	Glyphosate[40]

advantages than biofertilizers as they are highly efficient in fertiliser delivery(Table 3).

Nano pesticides: Cereals, pulses, and oilseeds are the foremost extensively cultivated food crops as they are rich in proteins, complex carbohydrates, lipids, nutrients, mineral deposits, and oils. These crops are severely affected by the pathogen attack and result in heavy loss of productivity.In severe cases, losses because of pest infection in storage reaches 50 to 60%[9].To protect the crop from pests high concentration of pesticides are commonly used which can increase the risks of food and water contamination, thus threatening human and environmental health[10]. Nanoagroparticles can easily penetrate the pathogen cell wall and damage plasma membrane resulting in the loss of cellular content and ultimately causing disruption in pathogen metabolism. These nano pesticides are encapsulated in different types of nanocarrier material and penetrate the pest and reduce the requirement of pesticides.

- Nano fungicide: The major crop species are susceptible to fungal attack such as *Alternaria, Synchytrium*, *Ustilago*, *Pucciniagraminisetc*., and result in huge loss of yield. High doses of fungicides are used to protect the crops which has deleterious effect on nearly all the forms of living organisms. Early 1930s copper nanoparticles dissolved in water have been used as a fungicide for controlling grapes and fruit trees diseases[18].Recently, *in vitro* assays showed the strong inhibitory effects of biosynthesized AgNPs against various fungal diseases[11]. Development of different complex of nanoagroparticles is an excellent source of combating the different fungal pathogens (Table 4). These eco-friendly fungicide using different nanomaterials only act inside the targeted fungal pathogen[12].
- Nano bactericides: Nanoparticles have demonstrated the profound activity against many phytopathogenic bacteria. Silver nanoparticles capped with protein of the size of 5-45 nm can kill the multidrug resistant variety of *Agrobacterium tumefaciens.* Green nano particles synthesized from black pepper (*Piper nigrum*) showed antibacterial properties against many resistant strains of bacteria (Fig. 1).

Nano herbicides:During cultivation unwanted plants also grow on their own; these are wild plants known as weeds. As a wild plant these are more efficient in nutrient absorption than the cultivated plant species and should be removed from the field. This can be done manually by plucking out the weeds but can only be done in small areas where as in large areas they are removed with the help of chemicals known as herbicides for example 2,4-D. Recently, Atrazine loaded nanocapsules were tested and these are reported tohave chemically more stable, enhanced bioavailability and photodecomposition[13]. Many different types of herbicide are encapsulated with chitosan and sodium triphosphate nanoparticles have highly reduced toxicity as compared to original

Table 3 — Different types Nanofertilizers made by using different nanomaterials and their use in different crops[41]

Type of nanomaterial	Usage in different crops
Fe nanoparticles and CeO_2	Increased weight of cabbage head and improved chlorophyll content
Fe_2O_3 nanoparticles	Improved tomato plant growth and protection against *Fusarium*
CNP polymerized with methacrylic acid and incorporated with potassium	Improve soil structure
zinc complexed CNP	Nanofertilizer application increased grain zinc content
B nano fertiliser	Increased fruit quality of pomegranate
Zn nano fertiliser	Increased fruit quality of pomegranate
Zinc oxide	Improved seed yield in soybean
Zn	Improved plant morphological characters in basil plant
Cu	Improved plant morphological characters in basil plant
ZnO	Enhancement of growth and yield, leaching reduction in *Triticum aestivum*
ZnO	Improved Zn content in rice
manganese zinc ferrite	Increased yield in squash plant

Table 4 —Nanofungicidescomprising different nanoagroparticles complex affectingfungalpathogens[42]

Nanoagroparticles	Affected Pathogen
Nanosilica	*Silkworm*
Silver	*Sitophilus oryzae*
Pongamiapinnata leaf extract coated zinc oxide nanoparticles	*Callosobruchus maculatus*
MgO, Fe_2O_3, ZnO	*Hyalomma Ticks*
TiO_2	*Cotton leaf worm*
silver nanoparticle	*Bipolarissorokiniana*
chitosan nanoparticle	*Candida albicans, Fusarium solani and Aspergillus niger*
ZnO	*Aspergillus fumigatus*
ZnO	*Rhizoctonia solani*
conjugated carboxymethylated-β-glucans on the MSNs surface loaded with CHT	*Fusarium graminearum, Sarocladium oryzae, Rhizoctonia solani, Colletotrichum truncatum*
spinetoramnano suspension	*Plutella xylostella*
Oil emulsions	*Sitophilus granarius*

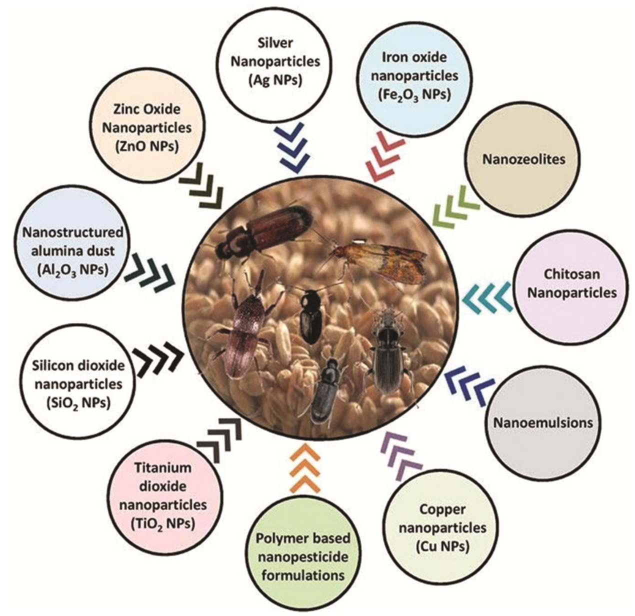

Fig. 1 — Types of nanomaterials which can be used for pest management during storage

chemicals without capsule of nanoparticles and targets for the specific receptors in the roots of the weeds[14].

Nanoagroparticles in soil improvement: Nano materials are being commonly used for soil remediation due to their strength, colloidal properties and uniform dispersal in aqueous solution. Nano structured silica easily disperse and facilitate the uniform dispersal of ground water and thus strengthen the soil. The other nanomaterial like bentonite and laponite have the potential in increasing soil moisture.

Nanoagroparticles in seed germination: The use of nanoparticles in enhancing the rate of seed germination of tomato seed[14].ZnO nanoparticle application enhances the germination rate in many plants[15]. Gold nanoparticles increased seed germination rate in *Gloriosa superba, Boswellia ovalifoliolata* and *Pennisetum glaucum* after Ag nanoparticle treatment. The TiO_2 treatment decreases the mean germination time in spinach seeds by facilitating water absorption[16]. 200 ppm silica nanoparticles were reported to enhance cucumber seed germination[17]. In *Artemisia absinthium* the germination percentage of 98.6% was achieved with silver Nanoparticles followed by Cu Nanoparticles (69.6%) and gold Nanoparticles (56.5%), respectively[18].

Nano agroparticles in food packaging and storage: After harvesting, the important task is to store the harvest and packaging it for distribution. If not done properly then Post-harvest losses can occur, sometimes exceeding those suffered by crops within the field, Directly losses are caused due to direct eating of husks, whereas indirect losses are caused because of creation of netting, exuviae, frass, and bug carcasses, which considerably reduces seed quality remarkably and render grains unsuitable for human use. Variations within the wheat storage system due to insect infestations result in the assembly of hot and damp "hotspots", which will definitely promote the expansion of storing fungus. This might boost the growth of fungus in stored grain and promotes crop losses even more. Chemical pesticides are commercially available at ease for the management of storage pests; but again however, these pesticides are highly expensive, ineffectual, and often detrimental to both the environment and health on a large level. Traditional pest control strategies in storing are currently majorly insufficient, and there's a need for development of new novel management approaches. The key advantage of using nano pesticides is that it can mostly reduces the number of pesticides used to protect crops and stored products. Several nano-emulsions have been investigated for pest management in stored grain. These nano-emulsion compositions, which are target-specific, can increase the efficacy of botanical insecticides for commercial exploitation. Using these formulations resolution of issues such as low aqueous solubility, deterioration, and turbulence, can be done to some extent.

Apart from pest issue abiotic factors such as moisture and temperature also influence the yields to counter it special storage containers are developed some are cold storage. With the help of nanotechnology special coatings are made which enhances the shelf life of preserving material. *Cinnamomum zeylanicum* essential oil encapsulated by an ionic gelation technique into chitosan nanoparticles has improved the shelf life of cucumber against *Phytophthora drechsleri*[19].Proline-coated chitosan nanoparticle coating has improved the shelf life of strawberries[20].

Risk management

As with any other technology certain risks are involved with use of nanoparticles in agriculture. There has been a lot of literature of potential applications of nanoparticles as nanoagro particles but only little knowledge is there about toxicity effects on non-target organisms and even to plants. Nanoparticles may get biomagnifiedin humans from plants and are found to be toxic to plants[21,22]. Nearly all types of nanoparticles have shown to act as a toxin on plants with effects ranging from failure of seed germination, ROS generation, stunted growth, chromosomal abnormalities[23]. The earthworms become sterile when treated with silver nanoparticles[24]. Majority of toxic effects are found only at high concentrations. One notable exception is Kocide 3000 has shown adverse effects when used for short term and in low conc[25]. Thus, nanoparticles should be exposed to the environment only in reasonable quantities as careless usage of nano-agroparticles results in toxicity issues and environmental contamination. However, there is a need to do risk-benefit assessment and evaluation of its effect on the environment as well on human health. As nanotechnological application in plant pathology is in the early stages and need more nanophytopathological studies on physiological aspects of host and pathogen, their interaction, process of infection and disease diagnosis. In future the detailed study of these aspects will help in developing new nanopesticides that are less harmful to the environment than conventional formulations[26].

Conclusion

The great challenges faced due to a growing global population and climate change, can be addressed by the judicial application of nanotechnologies as well as the introduction of nanomaterials in agriculture. With the advances in nanotechnology a new way of farming has become apparent and is known as 'Precision Farming'. This technique uses biosensors and artificial intelligence to analyse and predict environmental conditions to make decisions about how much fertiliser to use or water to irrigate. It maximises the yield while minimising the cost of maintenance of crops at the same time helps in reducing environmental damage. The advancements in nanotechnology and computer science together will improve the farming practices and will be available to even the poorest farmers in near future. Nanotechnology plays a central role in the agricultural sector, used in various products such as to protect plants and plant growth monitoring and disease detection. New applications of nanotechnology are explored by various scientists and in near future there are chances of tremendous changes in agriculture sector.

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Conflict of interest

All authors declare no conflict of interest.

References

1 Feynman R, There's plenty of room at the bottom. In Feynman and computation. (CRC Press) 2018, 63.

2 Taniguchi N, On the basic concept of nanotechnology. *Proceeding of the ICPE*, (1974) 18.

3 Sharma P, Pandey V, Sharma MM, Patra A, Singh B, Mehta S & Husen A, A review on biosensors and nanosensors application in agroecosystems. *Nanoscale Res Lett*, 16 (2021) 1.

4 Issa B, Obaidat IM, Albiss BA & Haik Y, Magnetic nanoparticles: surface effects and properties related to biomedicine applications. *Int J Mol Sci*, 14 (2013) 21266.

5 Thundiyil JG, Stober J, Besbelli N & Pronczuk J, Acute pesticide poisoning: a proposed classification tool. *Bull World Health Organ*, 86 (2008) 205.

6 Sekhon BS, Nanotechnology in agri-food production: an overview. *Nanotechnol Sci Appl*, 7 (2014) 31.

7 Liu R & Lal R, Potentials of engineered nanoparticles as fertilizers for increasing agronomic productions. *Sci Total Environ*, 514 (2015) 131.

8 Dasgupta D, Kumar K, Miglani R, Mishra R, Panda AK & Bisht SS, Microbial biofertilizers: Recent trends and future outlook. *Recent Adv Microbial Biotechnol*, (2021) 1.

9 Mahalakhsmi A & Baskar G, Greener synthesis and characterization of cadmium-tellurium quantum dots using aqueous extract of waste orange peel. *Indian J Biochem Biophys*, 58 (2021) 56.

10 Kah M, Walch H & Hofmann T, Environmental fate of nanopesticides: durability, sorption and photodegradation of nanoformulated clothianidin. *Environ Sci Nano*, 5 (2018) 882.

11 Lee KJ, Park SH, Govarthanan M, Hwang PH, Seo YS, Cho M, Lee WH, Lee JY, Kamala-Kannan S & Oh BT, Synthesis of silver nanoparticles using cow milk and their antifungal activity against phytopathogens. *Mater Lett*, 105 (2013) 128.

12 Choudhury SR, Nair KK, Kumar R, Gogoi R, Srivastava C, Gopal M, Subhramanyam BS, Devakumar C & Goswami A, Nanosulfur: a potent fungicide against food pathogen, *Aspergillus niger*. *AIP Conference Proceedings*, 1276 (2010) 154.

13 Sousa GF, Gomes DG, Campos EV, Oliveira JL, Fraceto LF, Stolf-Moreira R & Oliveira HC, Post-emergence herbicidal activity of nanoatrazine against susceptible weeds. *Front Environ Sci*, 6 (2018)12.

14 Chinnamuthu CR & Kokiladevi E, Weed management through nanoherbicides. *Appl Nanotechnol Agric*, 10 (2007) 978.

15 Singh NB, Amist N, Yadav K, Singh D, Pandey JK & Singh SC, Zinc oxide nanoparticles as fertilizer for the germination, growth and metabolism of vegetable crops. *JNAN*, 3 (2013) 353.

16 Gopinath K, Gowri S, Karthika V & Arumugam A. Green synthesis of gold nanoparticles from fruit extract of

Terminalia arjuna, for the enhanced seed germination activity of *Gloriosa superba. JNC*, 4 (2014) 1.

17 Alsaeedi A, El-Ramady H, Alshaal T, El-Garawani M, Elhawat N & Al-Otaibi A. Exogenous nanosilica improves germination and growth of cucumber by maintaining K^+/Na^+ ratio under elevated Na^+ stress. *Plant Physiol Biochem*, 125 (2018) 164.

18 Hussain M, Raja NI, Mashwani ZU, Iqbal M, Sabir S & Yasmeen F, *In vitro* seed germination and biochemical profiling of *Artemisia absinthium* exposed to various metallic nanoparticles. *Biotech*, 7 (2017) 1.

19 Mohammadi A, Hashemi M & Hosseini SM, Chitosan nanoparticles loaded with *Cinnamomum zeylanicum* essential oil enhance the shelf life of cucumber during cold storage. *Postharvest Biol Technol*, 110 (2015) 203.

20 Bahmani R, Razavi F, Mortazavi SN, Gohari G & Juárez-Maldonado A, Evaluation of proline-coated chitosan nanoparticles on decay control and quality preservation of strawberry fruit (cv. Camarosa) during cold storage. *Horticulturae*, 8 (2022) 648.

21 Patlolla AK, Berry A, May L & Tchounwou PB, Genotoxicity of silver nanoparticles in *Vicia faba*: a pilot study on the environmental monitoring of nanoparticles. *IJERPH,* 9 (2012)1649.

22 Wang Q, Ma X, Zhang W, Pei H & Chen Y, The impact of cerium oxide nanoparticles on tomato (*Solanumly copersicum* L.) and its implications for food safety. *Metallomics*, 4 (2012) 1105.

23 Jogaiah S, Paidi MK, Venugopal K, Geetha N, Mujtaba M, Udikeri SS & Govarthanan M, Phytotoxicological effects of engineered nanoparticles: An emerging nanotoxicology. *Sci Total Environ*, 801 (2021) 149809.

24 Yamal G, Biswas L & Kathpalia R, Exploiting the potential of bio-synthesized silver nanoparticles to enhance the shelf life of Gladiolus. *Indian J Biochem Biophys*, 59 (2022) 486.

25 Simonin M, Colman BP, Tang W, Judy JD, Anderson SM, Bergemann CM, Rocca JD, Unrine JM, Cassar N & Bernhardt ES, Plant and microbial responses to repeated Cu $(OH)_2$ nanopesticide exposures under different fertilization levels in an agro-ecosystem. *Front Microbiol*, 9 (2018) 1769.

26 Kah M, Beulke S, Tiede K & Hofmann T, Nanopesticides: state of knowledge, environmental fate, and exposure modeling. *Critical Rev Environ Sci Technol*, 43 (2013) 1823.

27 Yao KS, Li SJ, Tzeng KC, Cheng TC, Chang CY, Chiu CY, Liao CY, Hsu JJ & Lin ZP. Fluorescence silica nanoprobe as a biomarker for rapid detection of plant pathogens. *Adv Mater Res*, 79 (2009) 513.

28 Wang Z, Wei F, Liu SY, Xu Q, Huang JY, Dong XY, Yu JH, Yang Q, Zhao YD & Chen H, 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*, 80 (2010) 1277.

29 Fang Y, Umasankar Y & Ramasamy RP, Electrochemical detection of p-ethylguaiacol, a fungi infected fruit volatile using metal oxide nanoparticles. *Analyst*, 139 (2014) 3804.

30 Rad F, Mohsenifar A, Tabatabaei M, Safarnejad MR, Shahryari F, Safarpour H, Foroutan A, Mardi M, Davoudi D & Fotokian M, Detection of *Candidatus Phytoplasma aurantifolia* with a quantum dots fret-based biosensor. *J Plant Pathol*, 94 (2012) 525.

31 Tahir MA, Bajwa SZ, Mansoor S, Briddon RW, Khan WS, Scheffler BE & Amin I, Evaluation of carbon nanotube based copper nanoparticle composite for the efficient detection of agroviruses. *J Hazard Mater*, 346 (2018) 27.

32 Chartuprayoon N, Rheem Y, Ng JC, Nam J, Chen W & Myung NV, Polypyrrolenano ribbon based chemiresistive immunosensors for viral plant pathogen detection. *Anal Methods*, 5 (2013) 3497.

33 Konduri VV, Kalagatur NK, Nagaraj A, Kalagadda VR, Mangamuri UK, Durthi CP & Poda S, *Hibiscus tiliaceus* mediated phytochemical reduction of zinc oxide nanoparticles and emonstration of their antibacterial, anticancer, and dye degradation capabilities. *Indian J Biochem and Biophys*, 59 (2022) 565.

34 Ariffin SAB, Adam T, Hashim U, Sfaridah F, Zamri I & Uda MN, Plant diseases detection using nanowire as biosensor transducer. *Adv Mater Res*, 832 (2014) 113.

35 Zacco E, Pividori MI, Alegret S, Galvé R & Marco MP, Electrochemical magneto immunosensing strategy for the detection of pesticides residues. *Anal Chem*, 78 (2006) 1780.

36 Wang M & Li Z, Nano-composite ZrO_2/Au film electrode for voltammetric detection of parathion. *Sensors Actuators B: Chem*, 133 (2008) 607.

37 Zhao W, Ge PY, Xu JJ & Chen HY, Selective detection of hypertoxic organophosphates pesticides *via* PDMS composite based acetylcholinesterase-inhibition biosensor. *Environ Sci Technol*, 43 (2009) 6724.

38 Sun X, Liu B & Xia K, A sensitive and regenerable biosensor for organophosphate pesticide based on self-assembled multilayer film with CdTe as fluorescence probe. *Luminescence*, 26 (2011) 616.

39 Sahoo D, Mandal A, Mitra T, Chakraborty K, Bardhan M & Dasgupta AK, Nanosensing of pesticides by zinc oxide quantum dot: an optical and electrochemical approach for the detection of pesticides in water. *J Agric Food Chem,* 66 (2018) 414.

40 Chang YC, Lin YS, Xiao GT, Chiu TC & Hu CC, A highly selective and sensitive nanosensor for the detection of glyphosate. *Talanta*, 161 (2016) 94.

41 Namasivayam SKR & Bharani RSA, Silver nanoparticles loaded pyrrole based pesticidal metabolites (AgNps-PFM) nanoconjugate induced impact on the gut microbion and immune response against lepidopteron pest *Spodoptera litura* (Fab.). *Indian J Biochem Biophys*, 58 (2021) 478.

42 Priyanka P, Kumar D, Yadav A & Yadav K, Nanobiotechnology and its application in agriculture and food production. *Nanotechnol Food Agric Environ*, (2020) 105.