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# Future prospects of nanotechnology in agriculture

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**Abstract**
Nanotechnology is an emerging tool to improve productivity of crop and has capability to coup-up from present agricultural issues. The producing nanomaterials have several properties like slow release action, target action at active sites and high surface area etc. And due to this, nanotechnology applied in various fields including agriculture, food and processing industry and in precision farming. Use of nano sensors, nano herbicides, nano pesticides helps to improve efficiency of overall plant. Plant becomes more vigorous, competitive than weeds and other biotic factors. Now a day's silver nanoparticles has an effective role to check various seed and soil born phytopathogens. Hence, nanotechnology has proved their worth in agriculture.

**Keywords:** Precision farming, antimicrobial activity, nutrient use efficiency, target delivery

## Introduction
Agriculture is always most potentiated and stable sector because it produces and provides raw materials for food and feed industries. Due to the increasing world population, increased nutrient mining, for increase the total food grain production, shrinking arable lands, restricted water availability, deteriorating soil organic matter, climate change and so many other reasons; it is necessary to use the advance technologies such as nanotechnology in agricultural sciences. Nanotechnology has many applications in all stages of production, processing, storing, packaging and transport of agricultural products and other marketing facilities. The purpose of nano materials in agriculture is to reduce the amount of spread chemicals, minimize nutrient losses in fertilization and increased yield through pest and nutrient management. The significant interests of using nanotechnology in agriculture includes specific applications like nanofertilizers and nanopesticides to trail products and nutrients levels to increase the productivity without decontamination of soil, water and protection against various biotic and abiotic stresses. Nanotechnology may act as sensors for monitoring soil quality of agricultural field and thus it maintain the health of crops (Prasad *et al.*, 2017) [19]. Nanotechnology will transform agriculture and food industry by innovation of new techniques such as: precision farming techniques, enhancing the ability of plants to absorb nutrients, more efficient and targeted use of inputs, disease detection and control diseases. Increase the nutrient use efficiency of applied fertilizer with the help of nano clays and zeolites and restoration of soil fertility by releasing fixed nutrients. Nanoherbicides are being developed to address the problems in perennial weed management and exhausting seed bank of weed. Levels of environment pollution can be evaluated quickly and effectively by gas sensors and nano smart dust (Shaimaa and Mostafa, 2015) [24].

### What is Nano-technology?
Nanotechnology is an integration of different range of applied sciences such as chemistry, physics, biology, medicine and engineering in which the structure of the matter is controlled at the nanometre scale to produce materials having unique properties such as high surface area, target site of action and slow release.
The term "Nano" is derived from the Greek word "nanos" meaning 'DWARF' (Small). "Nano-technology mainly consists of the processing of separation, consolidation, and deformation of materials by one atom/ one molecule or ions."

### What are nanoparticles (NPs)?
Nanoparticles, whether of natural or manufactured origin, possess in the range of 1−100 nm in at least one dimension. Generally, nano meter is one billionth of a meter *e.g.* Nano emulsion,

carbon nanotubes, quantum dots, nanorods, micro and nano-encapsulation etc. Morphology-aspect ratio or size, hydrophobicity, solubility-release of toxic species, surface area or roughness, surface species contaminations or adsorption, during synthesis or history, reactive oxygen species (ROS) $O_2$ / $H_2O$, capacity to produce ROS, structure, composition, competitive binding sites with receptor and dispersion and aggregation are the important characteristics of nanoparticles (Somasundaran *et al*., 2010) [27].

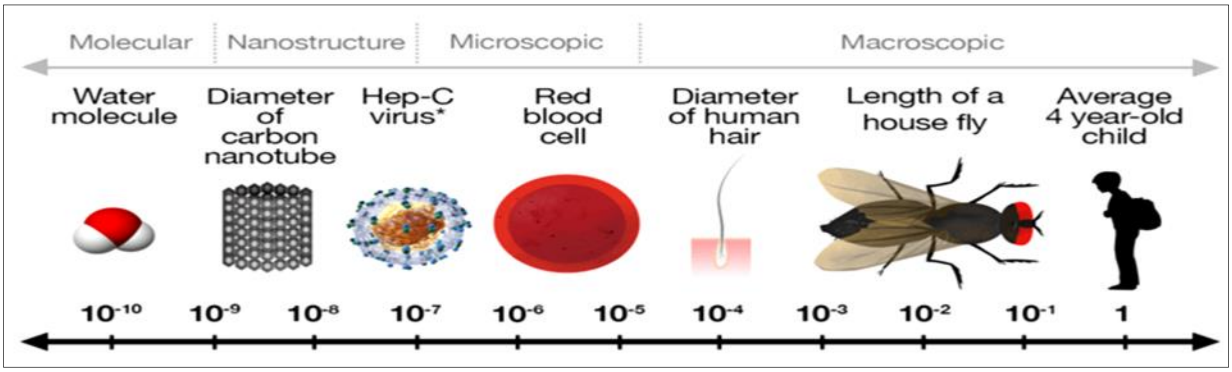


**Fig 1:** Scale of nanoparticles

**Potential application of nanotechnology in agriculture**

Use of nanofertilizers for slow release of nutrients and improve efficiency *viz.* Nano-5, Nano-Gro as plant growth regulators; nanopesticides encapsulated in nanoparticles for controlled release, nano emulsions for great control of pests e.g. Allosperse delivery system, Nano revolution-2 and adjuvant; will enhances agricultural input use efficiency. Nano sensor in precision farming and nano material for site specific soil and water conservation e.g. Geohumus and Nano Clay helps in efficient utilization of natural resources. Production of nano materials helps in recycling the agricultural waste ex. Central research institute of cotton, India has developed technology for production of nano cellulose from agricultural residues.

**Application of nanotechnology in agriculture and allied sciences**

Nanotechnology have its relevance in numerous fields of science out of them few are in agriculture and allied are food technology, crop improvement (genetic modified crops), seed technology, precision farming (site specific management), nano-fertilizer for balance crop nutrition, plant disease diagnose, weed management, water management, biosensors and pest management. Controlled Environment Agriculture (CEA) technology, as it exists today, provides an excellent platform for the introduction and utilization of nanotechnology to agriculture. With many of the monitoring and control systems already in place, nano technological devices for CEA that provide “scouting” capabilities improve the grower’s ability to determine the best time of sowing and harvest for the crop, the vitality of the crop and food security issues, such as microbial or chemical deterioration (Allah, 2012) [1].

- **Application of nanotechnology in precision farming**

Precision farming has been a long-desired goal to applying input as per demand of the crop that maximize output (i.e. crop yields) while minimizing input (i.e. fertilizers, pesticides, herbicides etc.). Precision farming makes use of computers, global satellite positioning systems (GPS), geological information systems (GIS) and remote sensing devices to measure highly localized environmental conditions thus determining whether crops are growing at maximum efficiency or precisely identifying the nature and location of problems of crops and edephological environment. Precision farming can also help to recycle agricultural waste and thus keep environmental pollution at minimum extent. Even though, tiny sensors and monitoring systems enabled by nanotechnology will have a large impact on future precision farming methodologies. One of the major roles for nanotechnology-enabled devices will be the increased use of autonomous sensors linked into a global positioning system (GPS) for real-time analysis. These nano sensors could be distributed throughout the field where they can monitor soil conditions and crop growth. The union of these two technologies in sensors will create equipment of increased sensitivity, allowing an earlier response to environmental changes, For example: (a) Nano sensors utilizing carbon nano tubes or nano-cantilevers has capability to trap and measure small molecules. (b) Nano particles or nano surfaces can be engineered to trigger an electrical or chemical signal in the presence of a contaminant such as bacteria and other pests or pathogens. (c) Other nano sensors perform by triggering an enzymatic reaction or by using nano engineered branching molecules called dendrites as probes to bind to target chemical sand proteins (Tiju and Morrison, 2006) [28].

- **Nano Sensors:**

Nanotechnology is also being developed to increase soil fertility and crop production. Nano sensors could also monitor crop health and magnetic nanoparticles could facilitate removal of soil contaminants (Hg, Pb and Zn). “Lab on a chip” technology also could have significant impacts on developing countries.

- **Nanofertilizers**

In the recent years nanofertilizers are freely available in the market, but particularly the agricultural fertilizers are still not shaped by the major chemical companies. Nanofertilizers may contain nano zinc, silica, iron and titanium dioxide, different core shell gold nanorods, QDs etc. as well as should endorse control release and improve its quality. Studies of the uptake, biological fate and toxicity of several metal oxide NPs, *viz.* AlO, TiO, FeO and ZnO nanoparticles were carried out intensively in the present decade for agricultural production (Zhang *et al*., 2016) [29]. So, quantification of nanoparticles is necessary to reduce the toxic effect of it.

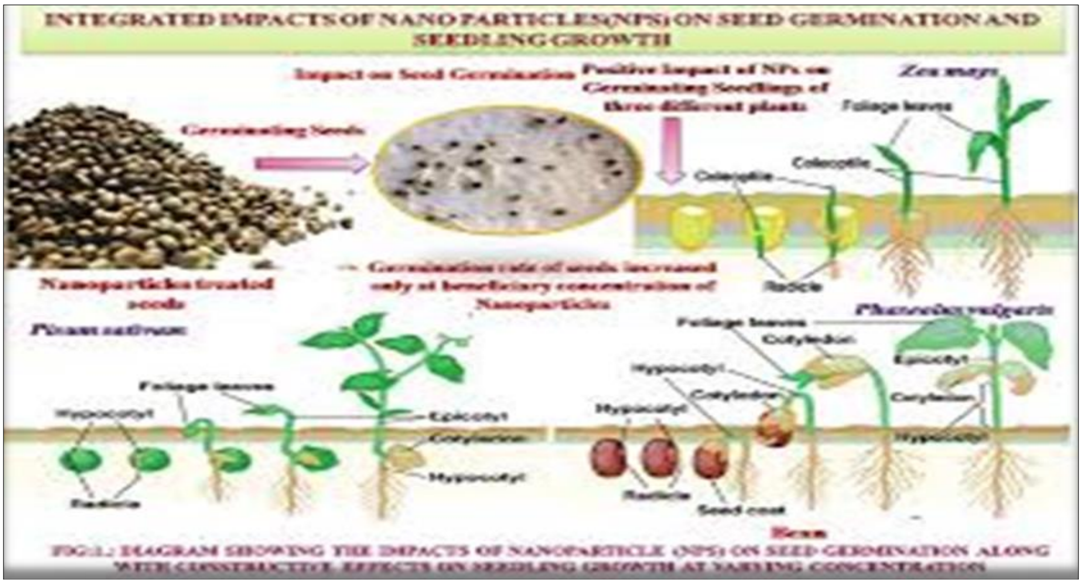


**Fig 2:** Impact of nanoparticles on seed germination

- **Nanoherbicides**

Multi-species approach with single herbicide or repeated use of herbicide with similar mode of action in the cropped environment resulted in poor control and herbicide resistance. Developing a target specific herbicide molecule encapsulated with nanoparticles is aimed at specific receptor in the roots of target weeds, which enter into roots system and translocated to parts that inhibit glycolysis or other pathways of food reserve in the root system. This will make the specific weed plant to starve for food and gets killed (Chinnamuthu and Kokiladevi, 2007) [6]. In rain fed areas, application of herbicides with insufficient soil moisture may lead to loss as photodecomposition. The controlled release action of encapsulated herbicides is expected to take care of the competing weeds with crops. Adjuvants for herbicide application are also available that including nanomaterials. One nano surfactant based on soybean micelles has been reported to create glyphosate-resistant crops susceptible to glyphosate when it is applied with the 'nanotechnology-derived surfactant'.

- **Nanopesticides**

The utilization of nanotechnology in plant protection and production of food is under-explored area in the future. It is well recognized that insect pests are the major ones in the agricultural fields and also in its products, thus nanoparticles may play a key role in the control of insect pests and host pathogens (Khota *et al*., 2012) [11]. The recent development of a nano encapsulated pesticide formulation has slow releasing action with improved solubility, specificity, permeability and stability (Bhattacharyya *et al*., 2016) [4]. Formulation of nano encapsulated pesticides led to reduce the dosage of pesticides, improve pesticide efficacy and human beings exposure to them which is eco-friendly for crop protection (Nuruzzaman *et al*., 2016) [17]. So development of non-toxic and promising pesticide delivery systems for increasing crop productivity per unit time basis while reducing the negative environmental impacts to ecosystem (Grillo *et al*., 2016) [9]. Recently, few chemical companies openly promote nanoscale pesticides for sale as "microencapsulated pesticides." (Karate ZEON, Subdue MAXX, Ospray's Chyella, Penncap-M) (Gouin, 2004) [8]. Syngenta markets some products such as the Primo MAXX, Banner MAXX, Subdue MAXX, etc. (Table 1). Despite they are known as micro emulsions. However, they are really nanoscale emulsions and this technique is commonly used for formulations of organic nanoparticles containing active agrochemicals or substances. A range of formulation types have been suggested including emulsions (e.g., nanoemulsions), nanocapsules (e.g., with polymers) and nanoclays. These products can be used to enhance the use efficacy of existing pesticide active ingredients or to improve sustainability. (Kookana *et al*., 2014) [13].

**Table 1:** Potential applications of nanotechnology in the pesticides sector

| Function | How this can be achieved | current examples |
|---|---|---|
| Enhanced apparent solubility | Nano and micro emulsions | Emulsion-based registered pesticides, Banner MAXX of Syngenta |
| Faster decomposition in soil and/or plant | Nano catalyst-conjugated *a.i.* in microcapsules | SDS-modified $TiO_2$/Ag conjugated with ai such as dimethomorph; imidacloprid and avermectin |
| Controlled release | Nanocapsules, nanospheres | Polymeric stabilized bifenthrin; nanocomposite 2,4-D; porous hollow Siencaged validamycin |
| Targeted delivery | Nanocapsules | Nanoenapcsulated glyphosate or sulfonylurea herbicide |
| Enhanced uptake/efficacy | Nano- and microemulsions, nanospheres | Nanopermethrin; nanosphere insecticides |
| Nanoparticle as *a.i.* (active ingredient) | Nanometals and nanoclays | Registered Nano-Ag biocide; Nano-Si |

- **Applications of nanotechnology in agronomy**

Nano sensors will be used to determine every small part of a farm how much needs to inputs. Therefore, economic efficiency of such inputs (fertilizers and pesticide) is increased and timely needs of crops fulfilled. Nano sensors and nano-based smart delivery systems could help in the efficient utilization of agricultural natural resources like water, nutrients and chemicals through precision farming and site specific management. Through the use of nano materials and global positioning system (GPS) and remote sensing farm managers could detect crop pests or evidence of stress such as drought and nutrient deficiency on the basis of spectural images. Nano fertilizers will be absorbed by plants rapidly and completely due to high surface area and more supply at action site that save fertilizer consumption and to minimize environmental pollution. Slow-release fertilizers are outstanding alternatives to soluble fertilizers. Nutrients are released at a slower rate throughout the crop growth asper need of crop without any kind of losses such as leaching, surface runoff, adsorption and decomposition. Slow release of nutrients in the environments could be provided by using zeolites that are a group of naturally occurring minerals that have a honeycomb-like layered crystal structure. This type of interconnection, tunnels and cages can be loaded with nitrogen, phosphorous, calcium and potassium, and a complete suite of minor and trace nutrients. Coating and cementing of nano and subnano-composites have capablility to regulating the release of nutrients from the fertilizer capsule (Liu *et al.*, 2006) [14]. A patented nano-composite consists of N, P, K, micronutrients and amino acids that boost the uptake and utilization of nutrients by grain crops has been reported (Jinghua, 2004) [10].

Seeds can also be imbibed with nano-encapsulations with specific bacterial strain (*Pseudomonas* spp.) termed as Smart Seed. It will thus reduce seed rate, ensure right field stand and improved crop yield. A Smart Seed can be programmed to germinate when adequate moisture is available that can be dispersed larger than a mountain range for reforestation (Natarajan and Sivasubramaniam, 2007) [16]. Coating seeds with nano membrane, which senses the availability of water and allow seeds to imbibe only at right time of germination, aerial broadcasting of seeds embedded with magnetic particle, detecting the moisture content during storage to take appropriate measure to reduce the spoilage and use of bio analytical nano sensors to determine ageing of seeds are some possible thrust areas of investigation. Siddiqui and Al-Whaibi (2014) [16] reported that application of nano silicon dioxide ($nSiO_2$: size 12 nm) significantly enhanced the germination of tomato seed. Prasad *et al*. (2012) [20] studied the effect of nanoscale zinc oxide particles on the germination, growth and yield of peanut and reported that treatment of nanoscale ZnO (25 nm mean particle size) at 1000 ppm concentration promoted both seed germination and seedling vigour and in turn showed early establishment in soil manifested by early flowering and higher leaf chlorophyll content. It is observed that 30.5% and 38.8% higher pod yield was recorded with the application of nanoscale ZnO at 2 g 15 $L^{-1}$ + NPK compared to NPK alone and 29.5% and 26.3% higher pod yield compared to chelated zinc at 30 g 15 $L^{-1}$ + NPK. Similar results were obtained by kisan *et al*. (2015) [12] in spinach and Estrada-Urbina *et al*. (2018) [7] in maize. These results may be due to that Zn act as a precursor of tryptophan (auxin inducing substance). These results indicated that nano-zinc oxide (1000 ppm) has a potential to be used as a bio fortification agent to improve quality of spinach leaves and their by reduce the malnutrition problem. Effect of nanoparticles is crop specific also. Pallavi *et al.* (2016) [18] carried out a study to investigate the impact of silver nanoparticles (AgNPs) on the growth of three different crop species wheat, cowpea and *Brassica* along with their impact on the rhizospheric bacterial diversity. Three different concentrations (0, 50 and 75 ppm) of AgNPs were applied through foliar spray. After harvesting, shoot and root parameters were compared. The effect of nanoparticles varied from one plant species to another; in wheat, no significant effect of AgNPs was observed on growth parameters, with the exception of root fresh weight and root length, which showed a negative response at 75 ppm treatment, while in cowpea and *Brassica*, a positive response was observed toward AgNPs (Fig. 4). But the concentration of AgNPs responsible for the observed effects was different for both cowpea and *Brassica*; in cowpea, 50 ppm concentration resulted in growth promotion and increased root nodulation indirectly (Fig. 5), whereas in *Brassica* 75 ppm concentration resulted in improved shoot parameters. The exact reasons behind the differential sensitivity of different plants toward nanoparticles remain unidentified to this date.

From this study, it can be concluded that plant, microbes, and AgNPs interaction is very complex and, by optimizing the AgNPs concentration, plant growth promotion can be achieved without causing harm to the environment.

Berahmand *et al.* (2012) [3] studied the effects silver nanoparticles and magnetic field on growth of fodder maize (*Zea mays* L.) and the treatments were as follows: magnetic field and silver nano particles+Kemira fertilizer (T1), magnetic field and silver nanoparticles+ Humax fertilizer (T2), magnetic field and silver nanoparticles (T3), Kemira fertilizer (T4), Librel fertilizer (T5), Humax fertilizer (T6), and a control (T7). Results indicated that treatments of silver nanoparticles with magnetic field (T3) had the highest fodder fresh yield (74.5 tons $ha^{-1}$) followed by the Kemira fertilizer treatment (T4) (64.9 tons $ha^{-1}$) in 2008. Silver nanoparticles with magnetic field treatment (T3) showed about 35 % more fresh yield in comparison to the control. So, silver nanoparticles help in improving qsuality and yield of produce.


**Fig 3:** Photograph showing the effect of foliar application of lower dosage of nanoscale ZnO on the pod yield. A and B) nanoscale ZnO @ 2 g/ 15 L and C) control

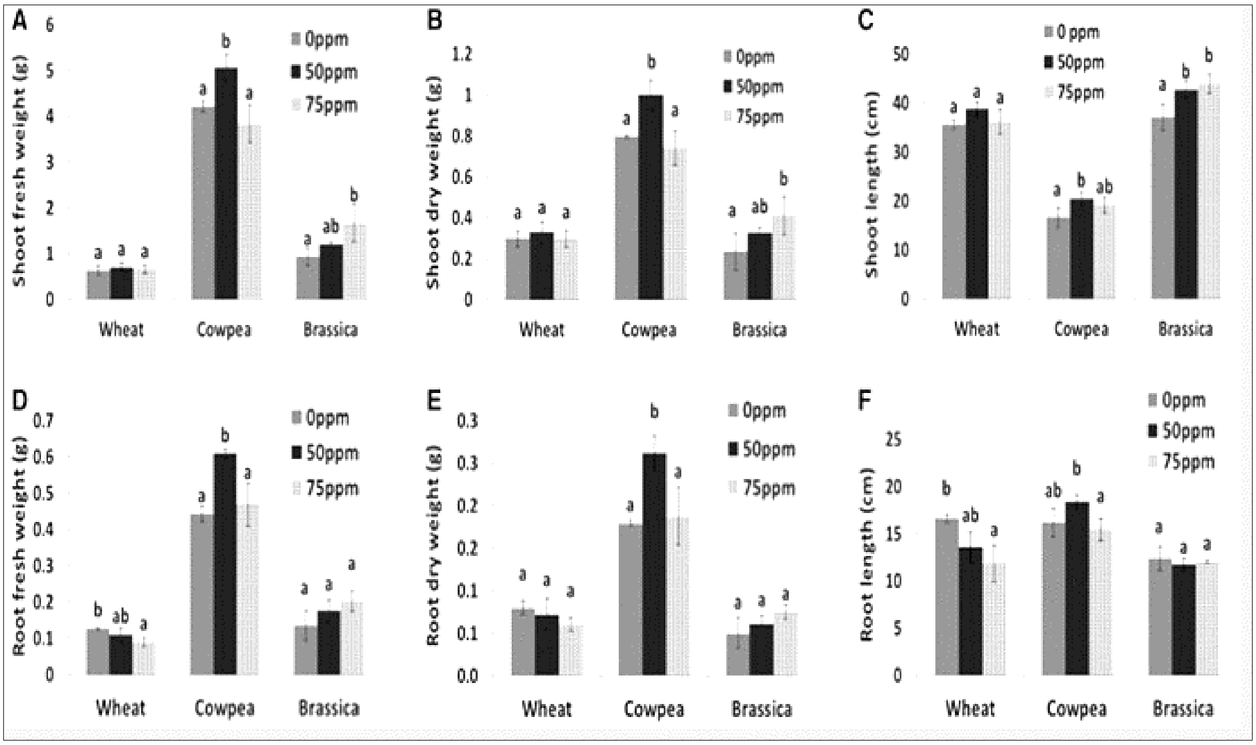


**Fig 4:** (a–f) Effect of three different concentrations (0, 50, 75 ppm) of silver nanoparticles on different growth parameters of wheat, cowpea and *Brassica.*

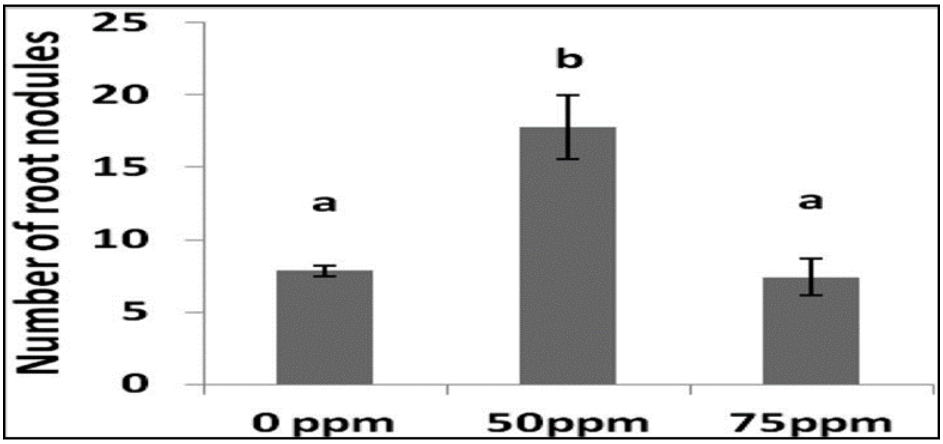


**Fig 5:** Effect of three different concentrations (0, 50, 75 ppm) of silver nanoparticles on the number of root nodules formed in cowpea.

**Applications of nanotechnology in pests and plant diseases management**

Now a day's use of chemicals such as pesticides, fungicides and herbicides is the fastest and cheapest way to control pests and diseases. Indiscriminate use of pesticides has caused many problems such as: adverse effects on human health and on pollinating insects and domestic animals, and entering this material directly or indirectly in ecosystems. Intelligent use of chemicals on the nano scale can be an appropriate solution for this problem. These materials are used as carriers in nano scale has self-regulation, this means that the medication on the necessary amount only be delivered into plant tissue. Nanoparticles for liberation of active ingredients or drug molecules will be at its helm in near future for therapy of all pathological sufferings of crop plants. There are myriad of nano materials including polymeric nanoparticles, iron oxide nanoparticles and gold nanoparticles which can be easily synthesized and exploited as pesticide, fertilizer or drug delivery piggybacks (Sharon *et al.*, 2010) [25]. Rao and Paria (2013) [22] used sulfur nanoparticles (SNPs) as a green nanopesticide on *Fusarium solani* and *Venturia inaequalis* phytopathogens. It has been found that small sized particles of SNP (35 nm) are very effective in prevention of the fungal growth and can be useful for the protection of important crops such as tomato, potato, apple, grape etc., from different diseases, mainly for organic farming because of antimicrobial property of silver. Nano-based viral diagnostics, including multiplexed diagnostic kit development, have taken momentum in order to detect the exact strain of virus or other pathogens and stage of application of some therapeutic to stop the disease.

Rouhani *et al.* (2012) [23] investigated the insecticidal activity of Ag nanoparticles against the *A. nerii*. Nanoparticles of Ag and Ag-Zn were synthesized through a solvothermal method, and using them, insecticidal solutions of different concentrations were prepared and tested on *A. nerii*. For comparison purposes, imidacloprid was also used as a conventional insecticide. The result showed that Ag nanoparticles can be used as a valuable tool in pest management programs of *A. nerii*. Additionally, the study showed that Imidacloprid at 1 µL $mL^{-1}$ and nanoparticles at 700 mg $mL^{-1}$ had the highest insect mortality effect.

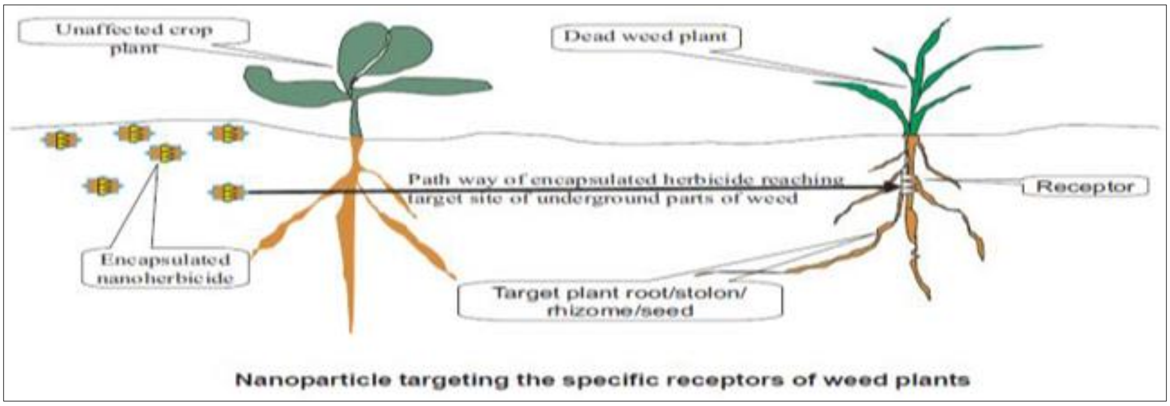


**Fig 6:** Smart delivery of nano encapsulated herbicide in the crop-weed environment

## Applications of nanotechnology in food industry

Oxygen is a problematic factor in food packaging, as it can cause food spoilage and discoloration. Nanoparticles have been developed a new plastic that preventing the penetration of oxygen as a barrier. In other words, the oxygen for entry into package should during longer route, and hence with the long route for oxygen molecules, food can be spoiled later. Polymer-silicate nano composites have also been reported to have improved gas barrier properties, mechanical strength, and thermal stability. Recently, nano-coatings are produced for fruit that covering the fruits completely, and prevent of fruit weight loss and shrinkage. (Predicala, 2009) [21]. Developing smart packaging to optimize product shelf-life has been the goal of many companies. Such packaging systems would be able to repair small holes/tears, respond to environmental conditions (e.g. temperature and moisture changes), and alert the customer if the food is contaminated. Nanotechnology can provide solutions for these, for example modifying the permeation behaviour of foils, increasing barrier properties (mechanical, thermal, chemical, and microbial), improving mechanical and heat-resistance properties, developing active antimicrobial and antifungal surfaces, and sensing as well as signalling microbiological and biochemical changes (Moraru *et al.,* 2003) [15].

In particular, silver nanoparticles have been shown to be a promising antimicrobial material. The most effect of controlling the fungus by nanoparticles is in < 24hrs (Fig. 2). In addition, the different concentrations of silver nanoparticles controlled *A. flavus*. (Allahvaisi 2016) [2]. Therefore, the concentration of nanoparticles is effective for controlling the fungi into foodstuffs packaging.

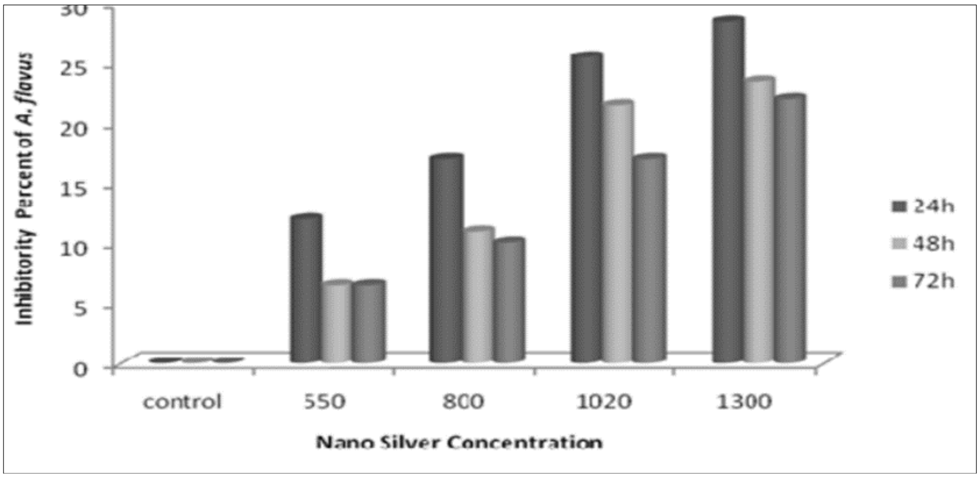


**Fig 7:** Inhibitory percent of *Aspergillus flavus* growth in petri dish tests

## Conclusion

Nanotechnology, by exploiting the unique properties of nanomaterials, has developed nanosensors capable of detecting pathogens at levels as low as parts per billion. Apart from detection, nanotechnology also has solutions for degrading persistent chemicals into harmless and sometimes useful components. Thus, nanotechnology can endeavour to provide and fundamentally streamline the technologies currently used in environmental detection, sensing and remediation.

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