**Application of Nanotechnology in Agriculture and allied sciences**

**1 \*Dr. Sunil Kr. Ghosh and 2 Dr. Rajib Karmakar and 3Krishnendu Pramanik and Gauranga Sundar Mandal4**

**1**Associate Professor, Department of Agricultural Entomology, Bidhan Chandra Krishi Viswavidyalaya (BCKV), Mohanpur, Nadia, West Bengal-741252, India

2 Asstt. Professor Department of Agricultural Chemicals, Faculty of Agriculture, BCKV, Mohanpur, Nadia, West Bengal, India, PIN-741252

3 Asstt. Professor Department of Biotechnology, Faculty of Agriculture, BCKV, Mohanpur, Nadia, West Bengal, India, PIN-741252

4 Asstt. Professor, Deptt. of Genetics and Plant breeding, B.C.K.V, Mohanpur, Nadia, West Bengal-741252, India

Email: sg\_bckv2014@rediffmail.com (\* corresponding author)

skghosh1969@gmail.com

Mob: 09434484475

Abstract:

Nanotechnology is an important study of interdisciplinary research and techinogy. It opens up a wide utility in many fields like insecticides, pharmaceuticals, electronics and agriculture. The potential uses and benefits of nanotechnology are many. These include management of insect pests through the formulations of nanomaterials based insecticides. Integrated pest management (IPM) used in agriculture are not sufficient for pest control. Use of chemical pesticides has adverse effects on animals and human health. It also have bad effect on soil fertility. Therefore, nanotechnology would provide green and efficient alternatives for the management of insect pests in agri-horty without any harmful effect on nature. This art is focused on nanomaterials in insect pest management as modern approaches of nanotechnology. The advances in science and technology in the last decades were made in several areas of insecticide usage. It includes either development of more effective and non-persistent pesticides and new ways of application, which includes controlled release formulation (CRF). The endeavors are direct towards the successful application of those compounds on crops. It helps reduction of environmental contamination and workers exposure. In that line, new types of formulation were developed. One of the most promising is the use of micro and nanotechnology to promote a more efficient assembly of the active compound in a matrix in order to protect core materials from adverse reactions due to factors like air or light. Nanomaterials need to be evaluated, so that this novel technology does not meet the same apprehensions and bottle-neck as faced by genetically modified crops.

***Keywords:*** Nano pheromones, Nano encapsulation, Nano particles, Smart delivery, Precision farming

**Introduction**

Insects are found in all possible environments throughout the globe. Their activity are large because of several important evolutionary aspects like wings, malleable exoskeleton, high reproductive potential, habits diversification, desiccation-resistant eggs and metamorphosis. On the other hand, many of the insects act vectors of diseases. A large number of insect damages crop plantations and wood structures, causing serious health and economic issues. In order to control the insect pest and retain the losses caused by insects on agriculture, toxic chemicals are used to kill them or inhibit their reproduction and feeding habits.

In the north east India major vegetables like brinjal, ladysfinger cabbage, chilli, pointed goard cauliflower etc are grown commercially but insect and mite pest attack limits the production (Ghosh *et al*., 1999; Ghosh *et al*., 2000; Ghosh and Senapati *2001a;* Chaudhury *et al*., 2001). Ghosh and Senapati (2009) reported that in the foot hill of the Himalaya so called terai region of India fruit and shoot borer was recorded very active in summer and rainy season, particularly during May-August, and caused about 50-80 % damage to fruits. Hadda/ spotted beetle (*Epilachne vigintioctopunctata*), aphid (*Aphis gossypii*), leafhopper (*Amrasca biguttula biguttula*), thrips (*Thrips tabaci*), spider mite (*Tetranychus spp*.) and white fly (*Bemisia tabaci*) are the important pests of eggplant that causes heavy damage (Ghosh, 1999). Aphid population causes heavy damage and limits the production (Ghosh, 2015; Ghosh, 2017). Bala *et.al.* (2015) and Ghosh (2019) reported that mite causes heavy damage to garlic crop and brinjal. Heavy incidence of the spotted beetle is reported in the temperature range of 24-31°C and relative humidity 58-75% Relative Humidity at the field condition ([Ramzan](http://scialert.net/fulltext/?doi=pjbs.2013.991.997&org=11" \l "1025591_ja)*[et al](http://scialert.net/fulltext/?doi=pjbs.2013.991.997&org=11" \l "1025591_ja)*[., 1990](http://scialert.net/fulltext/?doi=pjbs.2013.991.997&org=11" \l "1025591_ja); [Ghosh and Senapati, 2001](http://scialert.net/fulltext/?doi=pjbs.2013.991.997&org=11#1035759_ja) b.). The important pests cause damage to tomato crop is aphid (*Aphis gossypii),* whitefly (*Bemesia tabaci),* leaf miner *Lyriomyza triflii*), thrips *(Thrips tabaci* ), Jassid *(Empoasca binotata* ), Flea beetle *(Phyllotreta* *spp.)* (Laskar and Ghosh, 2005; Subba *et.al.,* 2014;Subba *et.al.,* 2015; Subba *et.al.,* 2016; Subba *et.al.,* 2017; Thakoor *et.al*., 2019). Important pest of ladysfinger are aphid (*Aphis gossypii*), Iassid (*Amrasca biguttula biguttuka* Ishida), whitefly (*Bemisia tabaci*), different species of flee beetle and red spider mite (*Tetranychus urticae*) (Ghosh *et. al*., 2009 a; Ghosh *et. al*., 2009 b; Das *et.al*., 2010; Ghosh, 2013; Ghosh, *et.al*., 2013). [Ghosh and Senapati (2002](http://scialert.net/fulltext/?doi=pjbs.2013.991.997&org=11#1035759_ja)) reported that neem (Azadiractin) based pesticide is very effective against epilachna beetles on vegetable crops recording about 70% control. Dicofol treatment resulted in the best control of mite pest population on brinjal/eggplant crop (about 80 % suppression), followed by formulation mixture of botanical pesticide, neem and chemical synthetic pesticide, dicofol (about 70 % suppression) (Ghosh and Chakraborty, 2014). Biswas *et. al*., (2009) reported that plant based pesticide neem is very effective against fruit borer *(Earias vittella)* of ladysfinger.

For controlling the pests farmers use large amount o pesticides and so cost of cultivation become very high. There is possibility to produce nano-particle of the pesticides with low cost. In this way it is possible to reduce the cost of cultivation by application of nanotechnology for low cost production of pesticides. So nanotechnology is a burning topic in modern plant protection as well as Agriculture. At present enough research work is needed for production of pesticides by application of nanotechnology.

**Nanotechnology**

The term “Nano” is derived from the Greek word meaning “dwarf” (Bhattacharyya *et al*., 2010). Technically the terms, “nano” means 10-9, or one billionth of any material. As for example, a biral particle is roughly 100 nm in size. In general, the term nanotechnology evolved from the use of nanometer size particles (size of 1 to 100 nm).

“Nano technology may be the manipulation or self-assembly of individual atoms, molecules or molecular clusters into structures to create materials and devices with new or vastly different properties.” The term nanotechnology is generally used when referring to materials in the size range of 0.1 to 100 nanometers. These materials should display different properties from bulk materials as a result of their size. These differences may be physical strength, electrical conductance, chemical reactivity, magnetism and optical effects.

Nanotechnology is potentially used in different cases and its benefits are many. These benefits include agricultural productivity enhancement involving nanoporous zeolites for slow release and efficient dosage of water and fertilizer. It is also used as nanocapsules for herbicide delivery and vector and pest management and nanosensors for pest detection. The atom arrangement allows the manipulation of nanoparticles thus influencing their size, shape and orientation for reaction with the targeted tissues. Now, nanotechnology has become promising new technologies in the modern science. Nanoparticles contain distinct physical, biological and chemical properties associated with their atomic strength.

**Approaches to obtain nanomaterials**

There are two main approaches for getting nano materials.

* **Self-assembly and bottom up approach:** Macro-sized complex systems is built by combination of simple atomic level components by principles of molecular recognition.

E.g. Chemical precipitation, Aerosol technique, Self-assembly etc.

* **Top down approach**: It is the system of breaking of big chunks of materials physically or chemically into nano objects by cutting/grinding etc.

E.g. Mechanical grinding, Erosion etc.

**Nano technology application in agriculture**

Among the many development of modern science, nanotechnology may be visualized as a rapidly evolving field which has potentiality to revolutionise both agriculture and food technology. Indian government has taken different dteps towards nanotechnology for boosting up agricultural production and productivity in the country. Recently, the Planning Commission of India recommended nano technology research and development as one of the important areas for investment. Nanotechnology is helpful in agriculture research as follows **(**Subramanian and Tarafdar, 2011):

1. **Nanofertilizers** for balanced crop nutrition and application in the field
2. **Effective weed control** using encapsulated herbicides and application.
3. **Enhancing seed emergence** using nano polymers.
4. **Bio-sensors** for detection of pesticides, nutrients and contaminating materials.
5. **Smart delivery systems** for controlling matters timely, spatially targeted and effective supply of nutrients and other chemicals.
6. **Precision farming** using autonomous sensors to monitor soil condition plant health and crop growth.
7. **Nanobiotechnology** to develop the efficiency and quality of agri-horticulture production and food storage.

**Nanotechnology in plant health management**

In case of plant health management, Nanotechnology can be aplied for**:**

1. Early detection of insect pests mite pests and other pests, diseases and nutrient deficiencies in the field and plant health.
2. Nano pheromones with sustained release of semiochemicals
3. Nano – encapsulation of plant nutrients, herbicides and pesticides
4. Nano – particles for control of pests and diseases
5. Smart delivery mechanism of different types of agriculture inputs

(Subramanian and Praghadeesh, 2012)

**Early detection of pests, diseases and nutrient deficiencies**

**Biosensors**

Nanotechnology plays an important role in development of biosensors. Nanomaterials may improve sensitivity and other aspects of biosensors. A biosensor consists of 2 elements: a biological receptor protein or cells specially designed to detect a substance and a sensor able to interpret the biological recognition and translate it into a measurable signal. Nanobiosensor refers to those whose properties are modulated because of nano- scale in which they are made. They have high sensitivity, high selectivity, reliability and rapidity. Interaction of target with biosensor is measured by recording changes in colour, fluorescence or electrical potential.

**Electronic nose (E-nose)**

Electronic nose (E-nose) is a device that mimics the operation of human nose having detecting power of an array of gases. This device consists of many gas sensors to detect different types of odors. The main purpose of E-nose is to identify the odor, estimate the concentration of the odorant and find different properties of the odor. E-nose comprises a gas sensor composed of Nano-particles (zinc oxide nanowires) whose resistance changes when a certain gas passes over it. The change in resistance generates a change in electrical signal which forms the fingerprint for gas detection. The nano-particles have improved uncontaminated surface area for better gas adsorption. E-nose technology is now widely used for detection of insect infestation in storage. Thus far, it has been employed in cotton for stink bud detection, in pulses for pulse beetle detection, in wheat for mite detection and also for storage pests of rice.

**Nano pheromones with sustained release of semiochemicals**

An important method of Integrated Pest Management (IPM) has use of pheromone trap for sustainable pest management. Nanoscience is useful for developing pheromones with a sustained release of semiochemicals in order to achieve eco-friendly pest control. These pheromone compounds are highly volatile and its release pattern may be regulated through nano-formulations. Nanotechnology increases the effectiveness of pheromones. It increases their shelf-life through entrapment by suitable host matrix. Thus, nanotechnology helps to develop simple, practical and low cost green chemical (eco-friendly) approach of pest control. Thus, it acts a significant role for plant protection, long lasting residual activity, excellent bio-efficacy and safety profiles.

**Management of Fruit Pests by Pheromone Nano-gels**

**-Bhagat *et al.* (2013)**

The nano-gel contains the chemical Methyl eugenol (ME). It may be used for the efficient pest control of *B. dorsalis* as a baiting trap. Pest is killed by trapping following this technology.

**Evidence of enhanced shelf-life of ME in the nano-gel**

The shelf life and activity of Methyl eugenol in nano-gel (Plate A), toluene (Plate B) and without any substrate (Plate C) i.e., ME alone were studied by exposing the above three treatment plates in a guava orchard for a fixed time. The fruit flies may be attracted to the plate A and to the plate C throughout the period and not to the plate B which held the gelator 1 in toluene. This means that the pheromone is biologically active in the nano-gel and is helpful for attracting the pest, although the compound 1 itself is inactive toward the fruit flies. The accumulation of the pests is increased with time around both the plates A and C.

The same plates were preserved at room temperature (~30°C) and after 21 days, were exposed again in the same guava orchard. At this time, the fruit flies were attracted to the plate A only which contained the nano-gel and not to the plate B or C for the whole time period of observation. This indicates that the nano-gel laced with ME still retained the pheromone for sustained release and has also retained significant pest attractant property due to the higher shelf-life of ME in nano-gel than the pure ME alone which evaporates away lot faster.

**Development of nanomatrix for delivery of the pheromone (ethyl 4 methyl octonate) of coconut rhinoceros beetle, *Oryctes rhinoceros.***

* Subramanian and Praghadeesh**(2012)**
* Aggregation pheromone (ethyl 4 methyl octonate) loaded in polymer membrane dispensers may be used for mass trapping of rhinoceros beetles. But these have high rate of release of 10-30 mg/day than nano.
* Nanoporous materials are a good carrier/dispenser for the volatile signaling molecules having controlled spatiotemporal release rate. A nanodispensar made of mesoporous sieves, with ordered pore channels, was developed for loading the rhinoceros beetle pheromone.
* Release rate of entrapped pheromone in nanomatrix was slower compared to commercial lures having polymer membrane.
* Field test of pheromone kept in nanomatrix captured more beetle pest than traps which are non-baited. The commercial lure having 800 mg pheromone might be exhausted within three months used, while the pheromone kept into nanomatrix could be used for a period of more or less six months from the installation date.

**Nano formulations in pest management**

Nano formulations may be classified into Nano emulsion, Nano suspension and Nano capsules.

1. Nano emulsion:-

Nano emulsions are highly stable systems. These have little coalescence of pesticide particles, non-sedimentation or creaming. These consist of lipid or polymeric vesicles or particles, in the size range of 20-200 nm. These may be of multiple phases and the example is oil in water.

E.g. Citronella oil made into nano emulsion which will provide mosquito protection for prolong time than general formulation.

*Advantages*:-

* It will increase the solubilisation of hydrophobic insecticides.
* There will be no need for toxic organic solvents and thus will become harmless.
* There is no problem of precipitation or creaming and so constant mixing is not required).
* Increased stability because of protection against oxidation.
* Prevents spray tank filters from clogging. The chemicals are completely mixed in water, and so these won’t be settled in the spray tank.

1. Nano suspension:-

Nano suspensions are sub-micron colloidal dispersions of pure active compounds. The particle size is ranged from 50-500 nm.

*Advantages*:-

* Surface area is higher.
* Solubility is higher..
* Induction of systemic activity is due to smaller particle size. They may be very active against insect pests having sucking type of mouth parts.
* Due to elimination of organic solvents, toxicity is lower.

1. Nano capsules:-

Nano capsules are comprised of a thin external layer having big space inside. It is usually comprised of polymers that contain the active compound inside a shell. The shell protects the chemical from damage by external agents and helps to improve its solubility and penetration activity through tissues.

**An overview of nano - formulations of insecticides under development**

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| **Formulation** | **Product name** | **Manufacturer/Company** | **Advantage** |
| *Nano- emulsion* | Citronella oil | National Science & Technology Development Agency, Thailand | Prolong mosquito protection |
| Triazophos | College of Chemistry & Environmental Science, China | Relatively stable in acidic and neutral and easily hydrolyzed in basic solution. |
| *Nano-suspension* | Novaluron | Makhteshim Chemical works Ltd., Israel | Increased penetration through the cuticle |
| Beta Cypermethrin | College of Chemistry &Molecular Science., Wuhan University, China | Faster dissolution rate |
| *Nano- particles* | PEG coated Nanoparticles Loaded with Garlic Essential Oil | Huazhong Agricultural University, China | Slow and persistent release of the active components to control *Tribolium castaneum* |
| Bifenthrin | Princeton University, USA | Higher efficiency, better uniformity of coverage for highly active compounds and less exposure to workers |
| Sugar coated novel particle  (Bio-pesticides) | The University of Queensland, Australia. | Protects the particle’s active ingredients from environmental and photo-degradation |
| *Nano- capsules* | Pyrethroid nanocapsules | Hong Kong Polytech.  University | Mosquito repellency and higher insecticide retention. |
| Nano Imidacloprid | Dept. of Life &Sciences, China | Prolonged release time |
| Karate® ZEON (lambda-cyhalothrin | Syngenta | Quick release, improve residual function, protection from UV light. |
| Demand 2.5CS  (γ-cyhalothrin) | Syngenta | Rapid knock down effect. Excellent residual action |
|  | ICONET(γ-cyhalothrin) 2.5CS | Syngenta | Long lasting effect, mosquito repellency |

**Nano encapsulation**

Nano encapsulation may be designated as a slow releasing of pesticide molecules. By this process, a chemical pesticide is released slowly but efficiently to the particular host for insect pests and disease control. Release mechanisms comprise dissolution, biodegradation, diffusion and osmotic pressure containing specific pH. Encapsulated citronella oil nano-emulsion is prepared by high-pressure homogenization of 2.5% surfactant and 100% glycerol, to create stable droplets that increase the retention of the oil and slow release. The release rate depends upon the protection time; a decreasing in release rate may prolong mosquito protection time. By utilizing this method, nanopesticides, nanofungicides and nanoherbicides may be used more efficiently in agriculture.

Primary and secondary insect pests of cotton, rice, peanuts and soybeans are controlled by another encapsulated product from Syngenta, marketed under the name KARATE ZEON. It is a quick releasing micro-encapsulated product containing the active compound lambda – cyhalothrin that breaks upon on contact with leaves.

Syngenta also holds patent on gutbuster, an encapsulated product which breaks upon to release its contents only in contact with alkaline environments, such as the stomach of certain insects. Each litre of Syngenta’s trademarked Zeon micro-encapsulated formulation contains about 50 trillion capsules which are designed as ‘quick releasing’.

Ethiprole is a phenyl pyrazole compound that blocks the insect gamma - aminobutryic acid receptor. The neuro-transmission faces problems of photo-inactivation during the time of field applications. Stable polymeric polycaprolactone and polylactic acid nanospheres encapsulating 3.5% of ethiprole are obtained with nanoprecipitation method. Initial biological testing for aphid control on cotton plants indicated that speed of action and controlled release of nanosphere formulations were not at par with chemical application. Nevertheless, the nanosphere formulation showed improved penetration through the plant because of their small size. (Boehm *et al*. 2003).

Pesticides having a short half-life such as avermectin (6h), the insect chloride channel inhibitor blocks neuro-transmission, faced problems of UV inactivation on the fields. Porous hollow silica NPs with a shell thickness of ~15 nm and a pore diameter of 4-5 nm were reported to protect avermectin from UV degradation and allowed its slow releasing. Slow releasing of encapsulated avermectin by the NPs carrier was reported for about 30 days (Ghormade *et al*., 201).

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**Nano based delivery of biopesticides**

Phytochemicals (plant based formulation) such as essential oils face problems of chemical instability in the presence of air, light, moisture and high temperatures. These climatic factors have influence to rapid evaporation and degradation of some active components. Rapid evaporation and degradation may be prevented by incorporation of essential oils into a controlled release nano formulation, and thus enhances stability and maintains minimum effective dosage.

An essential oil extracted from *Allium sativum* (garlic) was loaded on polymer NPs (240 nm) coated with polyethylene glycol and their insecticidal activity against adult *Tribolium castaneum* was evaluated. The control efficacy of garlic essential oil loaded NP s against *Tribolium* remained over 80% after 5 months due to the controlled slow release of the active components, in comparison to free garlic essential oil (11%).

**Nano particles**

Nano particles can be defined as natural, incidental or manufactured material having particles, for 50% or more of the particles, one or more external dimensions in the size range of 1 nm- 100nm. Nano particles are important to their application in crop protection because of their size dependent qualities, high surface to volume ratio and unique optical properties.

**Entomotoxic effects of Silica nanoparticles against *Sitophilus oryzae* L.**

* **Debnath *et al*. (2011)**

Considering the residual toxicity and resistance problem of insects to storage insecticides has led to evolve alternative strategies for protection of stored products. Diatomaceous earths (DE s), One such alternative composed mainly of amorphous silica. Earlier formulations of DE were not widely accepted because of their adverse effects on bulk density of grains. *Sitophilus oryzae*is becoming resistant to phosphine and conventional insecticides such as pyrethroids, Silica nano particles (SNPs) are used in this study, which is claimed to be relatively non hazardous. USDA has already declared non-crystalline silica as safe.

Hydrophilic SNPs both custom made and modified particles showed considerable insecticide property at 1g/kg dose or above on the first day. After day 4, more than 90% *S*. *oryzae* died when hydrophilic SNPs (both types) was applied at the dose of 1g/kg. Bulk sized silica even at the highest dose caused only 34% insect mortality. So custom made (15-20nm) hydrophilic SNPs and 20-30 nm modified particles SNPs were equally effective on *S. oryzae* at 95% level of significance. It was also found that SNP s had no adverse effect on plant growth, rather it enhances structural rigidity and strength of plant.

**Mean mortality (±S.E.) of *Sitophilus oryzae* adults exposed for 7 days on rice treated with bulk and nano silica at 3 dose rates.**

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| --- | --- | --- | --- | --- |
| **Nanoparticles** | **0 g kg-1** | **0.5 g kg-1** | **1 g kg-1** | **2 g kg-1** |
| SiO2—hydrophilic | 2.0 ± 2.7 | 35.4 ± 8.3 | 95.0 ± 5.0 | 97.0 ± 2.7 |
| SiO2—hydrophobic | 2.0 ± 2.7 | 62.0 ± 9.1 | 86.0 ± 8.2 | 100.0 ± 0.0 |
| SiO2—lipophilic | 2.0 ± 2.7 | 62.4 ± 5.6 | 71.0 ± 8.9 | 100.0 ± 0.0 |
| SiO2 (modified Stober) | 2.0 ± 2.7 | 35.4 ± 8.3 | 94.0 ± 4.2 | 97.0 ± 2.7 |
| SiO2—bulk | 2.0 ± 2.7 | 16.0 ± 5.5 | 21.9 ± 6.5 | 34.0 ± 5.5 |

Nano silica was found more effective than bulk silica because of the increased exposed surfaces that would interact with insect cuticle. Due to sorption and abrasion, damage occurs to the insect’s protective wax coat on the cuticle. The insects begin to lose water through desiccation as the water barrier is damaged and die due to desiccation. One important finding was that no fresh insect infestation was found in SNP treated stored rice even after 2 months of treatment. The nanocide can be removed by conventional milling process unlike sprayable formulations of conventional pesticides. Therefore, SNPs has an excellent potential as stored grains as well as seed protecting agent if applied with proper safety measures.

**Smart delivery mechanism**

Nanodevices as delivery systems to specific targets in living organisms was first experienced for medical uses. In plants, the same principles can be applied for a broad range of uses, in particular to tackle infections. Nanoparticles used as agrochemicals or other substances could reduce the damage to other plant tissues. It also reduces the amount of chemicals released into the environment.

**Biodegradable nanofibres as carrier for the controlled release of pesticides**

Controlled delivery technique aims towards measured release of necessary and sufficient amounts of agrochemicals over a period of time. It is also used to obtain the fullest biological efficacy and to minimize the harmful effects. Nanofibres incorporated with pesticides function as an effective controlled delivery system.

Imidacloprid, an insecticide and tebuconazole, a fungicide were incorporated into poly (lactic-co-glycolic acid) [PLGA] biopolymer with a lactic acid/glycolic acid ratio of 85:15 and nanofibres are produced by electrospinning process. The size of nanofibres ranged from 130 nm to 250 nm in dia. By virtue of their nano-scale diameter and large surface area, electrospunfibres offer many additional advantages like enhanced bioavailability, timed release, lower application rates, improved specificity, ease and safety and more responsiveness to environment.

**Risks involved**

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| **Nanomaterials** | **Possible risks** |
| Carbon nanomaterials, Silica nanoparticles | Pulmonary inflammation,granulomas, and fibrosis |
| Carbon, Silver and Gold nanomaterials | Distribution into other organsincluding the centralnervous system |
| Quantum dots, carbon and TiO2 nanoparticles | Skin penetration |
| MnO2,TiO2 and carbon nanoparticles | May enter brain throughnasal epithelium olfactoryneurons |
| TiO2, Al2O3, Carbon black, CO and Ni | May be more toxic thanmicron sized particles |

* ZnO nano particles found to be toxic to both gram-negative and positive bacterial systems, *Escherichia coli and Staphylococcus aureus.*
* A single high oral dose of nano TiO2 caused significant lesions in kidney and liver of female mice.
* Nano TiO2 is also toxic to algae and water fleas, especially after exposure to UV light.
* 15 nm Ag nano particles found to be toxic to mouse germline stem cells *invitro.*
* 50 & 70 nm SiO2 particles taken up into cell nucleus caused aberrant protein formation & inhibited cell growth, in vitro.

**What are the solutions?**

* Early and open examination of the potential risks of a new product or technology.
* Public and private organisations should collaborate to determine the testing, necessary for new nano products entry in commercial scale.
* For products already in our stores, there should be good product management, should identify and manage potential risks.
* Government should invest more seriously in the research.
* Standard quality certification to ensure product safety.

**Conclusion:**

Nanotechnology is well established in medical sciences which made breakthroughs in finding solution to serious human diseases without associated side effects. In agriculture, this technology is at nascent stage. Promising results are obtained by the use of nano materials for delivery of pesticides and fertilizers. Nano particles can be used as insecticide, with safety measures. Nano particles can stabilize bio-control preparations. Nano sensors can be used for detecting pesticides at lower level. It can also be done to degrade persistent chemicals to harmless ones.

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