**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 a promising field of interdisciplinary research. It opens up a wide array of opportunities in various fields like insecticides, pharmaceuticals, electronics and agriculture. The potential uses and benefits of nanotechnology are enormous. These include management of insect pests through the formulations of nanomaterials based insecticides. Traditional strategies like integrated pest management used in agriculture are insufficient, and application of chemical pesticides have adverse effects on animals and human beings apart from the decline in soil fertility. Therefore, nanotechnology would provide green and efficient alternatives for the management of insect pests in agriculture without harming the nature. This art is focused on traditional strategies used for the management of insect pests and potential of nanomaterials in insect pest control 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 and their efficacy and availability improvement and 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. An outcry is exhibited against the use of pesticides due to their hazardous effects on human as well as environment. There is a great concern regarding the nonmaterial which have potential to exert hazardous effects on human and the environment and when we have a nano-pesticide, it becomes a double edged weapon. 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 success can be attributed to several important evolutionary aspects like wings, malleable exoskeleton, high reproductive potential, habits diversification, desiccation-resistant eggs and metamorphosis, just to name a few. On the other hand, a large number of insects are vectors of many diseases, and many others insect pests damages crop plantations or wood structures, causing serious health and economic issues. In order to combat the numerous losses that are caused by insects on agriculture, several chemicals have been 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 cultivated at a commercial scale but insect and mite pest damage constitutes a limiting factor for its successful 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 sub-Himalayan region so called terai region of India fruit and shoot borer was recorded very active during summer and the 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 has been reported during temperature range of 24-31°C and relative humidity 58-75% RH in the field ([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 population on brinjal/eggplant crop (about 80 % suppression), followed by mixed formulation of botanical pesticide, neem and chemical 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**

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

 “Nano technology is 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 word nanotechnology is generally used when referring to materials in the size range of 0.1 to 100 nanometers. Also it is inherent that these materials should display different properties from bulk materials as a result of their size. These differences include physical strength, chemical reactivity, electrical conductance, magnetism and optical effects.

The benefits and potential uses of nanotechnology are many. These include agricultural productivity enhancement involving nanoporous zeolites for slow release and efficient dosage of water and fertilizer, 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. Thus, nanotechnology has become promising new technologies in the modern times. Nanoparticles possess distinct physical, biological and chemical properties associated with their atomic strength.

**Approaches to obtain nanomaterials**

There are two main approaches for getting nano materials.

* **Bottom up approach / Self-assembly:** It is the building up of macro-sized complex systems by combining simple atomic level components by principles of molecular recognition.

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

* **Top down approach**: It is the approach 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 is being visualized as a rapidly evolving field that has potential 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 permits broad advances in agricultural 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. **Biosensors** to detect pesticides, nutrients and contaminants.
5. **Smart delivery systems** for timely controlled, 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 increase the efficiency and quality of agricultural 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 can be 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 in detecting an array of gases. This device contains several gas sensors to detect different types of odors. The main purpose is to identify the odorant, estimate the concentration of the odorant and find characteristic properties of the odor. The main component of e-nose is 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 that forms the fingerprint for gas detection. The advantage of using nanoparticles is that they 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) is 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 plays a vital role in the increase of the effectiveness of pheromones. It increases their shelf-life through their entrapment by suitable host matrix. Thus, nanotechnology offers simple, practical and low cost green chemical approach of pest management. Thus it act with a significant potential for crop protection, long lasting residual activity, excellent efficacy and favorable safety profiles.

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

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

The nano-gel contains the chemical Methyl eugenol (ME). It is utilized for the efficient pest management of *B. dorsalis* as a bait trap. It is a technique used to kill the pest by trapping.

**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 number of hours. The fruit flies were attracted specifically 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 indicates that the pheromone is biologically active in the nano-gel and is responsible for attracting the pest although the compound 1 itself is inactive toward the fruit flies. The accumulation of the pests increased with time around both the plates A and C.

The same plates were preserved at room temperature (~30°C) and were exposed again in the same guava orchard after 21 days. Interestingly 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 entire 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 ethyl 4 methyl octonate, the pheromone of coconut rhinoceros beetle, *Oryctes rhinoceros.***

* Subramanian and Praghadeesh**(2012)**
* Aggregation pheromone (ethyl 4 methyl octonate) loaded in polymer membrane dispensers are being 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 novel carrier/dispenser for the volatile signaling molecules with 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 pest (beetles) than traps which are unbaited. The commercial lure containing 800 mg pheromone was exhausted in three months used, while the pheromone kept into nanomatrix could be used for a period of more or less six months from 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 that have little coalescence of pesticide particles, non-sedimentation or creaming. They consist of lipid or polymeric vesicles or particles, in the size range of 20-200 nm. They are may be of multiple phases. The simplest 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 precipitation or creaming (therefore no need for constant mixing).
* Increased stability because of protection against oxidation.
* Prevents spray tank filters from clogging. The chemicals will be mixed so completely in water that they 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 typically ranged from 50-500 nm.

*Advantages*:-

* Higher surface area.
* Higher solubility.
* Induction of systemic activity due to smaller particle size. They may be very active against insect pests having sucking type of mouth parts.
* Lower toxicity due to elimination of organic solvents.
1. Nano capsules:-

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

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

|  |  |  |  |
| --- | --- | --- | --- |
| **Formulation** | **Product name** | **Manufacturer/Company** | **Advantage** |
| *Nano emulsion* | Citronella oil | National Science & Technology Development Agency, Thailand | Prolong mosquito protection time. |
| Triazophos | College of Chemistry & Environmental Science, China | Relatively stable in acidic& neutral &easily hydrolyzed in basic solution. |
| *Nanosuspension* | 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 is a slow releasing pesticide. It is a process through which a chemical is slowly but efficiently released to the particular host for insect pests control. Release mechanisms include dissolution, biodegradation, diffusion and osmotic pressure with 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; consequently a decrease in release rate can prolong mosquito protection time. Nanopesticides, nanofungicides and nanoherbicides are being used efficiently in agriculture.

 Another encapsulated product from Syngenta delivers a broad spectrum control on primary and secondary insect pests of cotton, rice, peanuts & soybeans. Marketed under the name KARATE ZEON, this is a quick release microencapsulated product containing the active compound lambda – cyhalothrin which 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 microencapsulated formulation contains about 50 trillion capsules that are designed to be ‘quick release’.

 Ethiprole is a phenyl pyrazole compound that blocks the insect gamma - aminobutryic acid receptor and neurotransmission faced problems of photoinactivation during field applications. Stable polymeric polycaprolactone and polylactic acid nanospheres encapsulating 3.5% of ethiprole were 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 enhanced systemicity of the active ingredients and improved penetration through the plant due to their small size. (Boehm *et al*. 2003).

 Pesticides with a short half-life such as avermectin (6h), the insect chloride channel inhibitor that blocks neurotransmission, 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 release. Slow release of encapsulated avermectin by the NPs carrier was reported for about 30 days (Ghormade *et al*., 201).

**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 cause rapid evaporation and degradation of some active components. Incorporation of essential oils into a controlled release nano formulation prevents rapid evaporation and degradation, and thus enhances stability and maintains minimum effective dosage.

 An essential oil from 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, in an unbound stage or as an aggregate or as an agglomerate and where, for 50% or more of the particles, one or more external dimensions in the size range of 1 nm- 100nm. Nano particles hold great promise regarding their application in plant protection due to 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)**

 Consumer awareness of the consequences of residual toxicity and increasing resistance of insects to storage insecticides has led the researchers to evaluate alternative strategies to protect stored products. One such alternative was use of Diatomaceous earths (DE s), 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) used in this study is claimed to be relatively non hazardous. USDA has already declared non-crystalline silica as safe.

 Hydrophilic SNPs both custom made and modified Stober showed considerable insecticidal 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 caused only 34% insect mortality even at the highest dose. So custom made (15-20nm) hydrophilic SNPs and 20-30 nm modified Stober SNPs were equally effective on *S. oryzae* at 95% level of significance. Also found out that SNP s has 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.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **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 far more effective than bulk silica because of the enormously increased exposed surfaces which would interact with insect cuticle. Damage occurs to the insect’s protective wax coat on the cuticle, both by sorption and abrasion. The insects begin to lose water through desiccation as the water barrier is damaged and die due to desiccation. Insects are unlikely to become genetically selected or physiologically resistant to such a physical mechanism of action.

 One exciting 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**

The great potential of using nanodevices as delivery systems to specific targets in living organisms was first explored for medical uses. In plants, the same principles can be applied for a broad range of uses, in particular to tackle infections. Nanoparticles tagged to agrochemicals or other substances could reduce the damage to other plant tissues and 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, 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 diameter. 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**

|  |  |
| --- | --- |
| **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 & 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.

**References**

Bala, S.C., Karmakar, K. and Ghosh, S.K. (2015). Population dynamics of mite , Aceria tulipae Keif. on garlic (*Allium sativum* L.) and its management under Bengal basin. *International Journal of Science, Environment and Technology.* **4** (5): 1365-1372.

Bhagat, D., Samanta, S.K and Bhattacharya, S. (2013). Efficient Management of Fruit Pests by Pheromone Nanogels. *Scientific Reports*. **3**: 1294-1302.

Bhattacharyya, A., Bhaumik, A., Usha Rani, P., Mandal, S. and Timothy, T. (2010). Nano particles - A recent approach to insect pest control. *African Journal of Biotechnology*. **9**(24): 3489-3493.

Biswas, S., Das, K. and Ghosh. S.K. (2009). field efficacy of different insecticides and neem against *Earias vittela* fab. on okra. *Journal of entomological Res*e*arch.*  **33** (4): 331-333.

Boehm, A.L., Martinon, I., Zerrouk, R., Rump, E and Fessi, H. (2003). Nanoprecipitation technique for the encapsulation of agrochemical active ingredients. *Journal of Microencapsulation*.**20**: 433–441.

Chaudhury, N., Ghosh, S.K., Ghosh, J. and Senapati, S.K. (2001). lncidence of insect pests of cabbage in relation to prevailing climatic conditions of terai region. *Indian Journal of Entomology.* **63**(4):421-428.

Das, K., Biswas, S., Chakraborty, G. and Ghosh, S.K. (2010(. Efficacy of insecticides against Iassid (*Amrasca biguttula biguttuka* Ishida) on okra in terai agro-ecology of West Bengal. *Journal of Applied Zoology Res*earch. **21** (1): 33-35.

Debnath, N., Das, S., Seth, D., Chandra, R., Bhattacharya, S.C and Goswami, A. (2011). Entomotoxic effect of silica nanoparticles against *Sitophilus oryzae* (L.). *Journal of Pest Sciences*.**84**:99–105.

Ghormade, V., Deshpande, M. and Vand Paknikar, K. M. (2011). Perspectives for nano-biotechnology enabled protection and nutrition of plants. *Biotechnology Advances.* **29**: 792–803.

Ghosh, S.K. (1999). Studies on the pest constraints of brinjal and their management under terai region of West Bengal. Doctoral thesis, BCKV, Mohanpur, India.

Ghosh, J., Ghosh, S.K., Chatterjee, H. and Senapati, S.K. (1999). Pest constraints of Okra under terai region of West Bengal. *Indian Journal of Entomol*ogy. **61**: 362-71.

Ghosh, J., Ghosh, S.K., Chaudhuri, N. and Senapati, S.K. (2000). Preliminary studies on the insect pest complex of cauliflower in terai region. of West Bengal.. *Hariyana Journal of Horticultural Sciences.***29** (1 & 2): 118-119.

Ghosh, S.K. and Senapati, S.K. ( 2001a). Seasonal incidence and biology of brinjal shoot and fruit borer *(Leucinodes orbonalis* Guen.) under terai region of West Bengal, India. *Annals of Entomology.* **19**(1):13-18.

Ghosh, S.K. and Senapati, S.K. (2001 b). Biology and seasonal fluctuation of Henosepilachna vigintioctopunctata Fabr. on brinjal under Terai region of West Bengal. *Indian Journal of Agriculture Research.* **35**: 149-154.

Ghosh, S.K. and Senapati, S, K. (2002). Field evaluation of pesticides from different origin against pest complex of brinjal under terai region of W. B. *Crop Research****.* 23**(1): 108-115.

Ghosh, S.K. and Senapati, S.K. (2009). Seasonal fluctuation in the population of *Leucinodes orbonalis* Guen. Under the sub-himalayan resion of West Bengal, India and its control on eggplant (*Solanum melongena* L.). *Precision Agriculture.* **10**:443-449.

Ghosh, S.K., Sonowal, M., Chakraborty, G. and Pal, P.K. (2009 a). Bio-efficacy of microbial formulation against red spider mite (*Tetranychus urticae* Koch*.*) infesting ladysfinger (*Abelmoschus esculentus* L.) *Green Farming* **2**(10):685-688.

Ghosh, S.K., Mahapatra, G.S.S. and Chakraborty, G. (2009 b). Field efficacy of plant extracts and microbial insecticides against aphid (*Aphis gossypii*) infesting okra (*Abelmoschus esculentus*). *Redia, Itali*  XC11: 249-252 (with sub-title *Journal of Entomology*).

Ghosh, S.K. (2013). Incidence of red spider mite (*Tetranychus urticae* Koch) on okra (*Abelmoschus esculentus* (L.) Moench) and their sustainable management.*Current Biotica***7**(1&2): 40-50.

Ghosh, S.K., Mandal, T. and Chakraborty, K. (2013). Efficacy of chemical insecticides and neem oil against white fly (*Bemisia tabaci* Genn.) Infesting ladysfinger (*Abelmoschus esculentus* L.). *International* *Journal of Bio-resource and Stress Management* **4** (2): special 348-351.

Ghosh, S.K. and Chakraborty, K. (2014). Bio-Efficacy of plant extracts against red spider mite (*Tetranychus spp.* ) infesting brinjal (*Solanum melongena* L.)**.** *Research journal of Agricultural and Environmental Sciences.* **1** (1): 26-31.

Ghosh, S.K. (2015). Integrated field management of aphid (*Myzus persicae* Sulz. And *Aphis gossypii* Glov. Together) on potato (*Solanum tuberosum* L.) using bio-pesticides *International Journal of Science, Environment and Technology.* **4** (3): 682-689.

Ghosh, S.K. (2017). Seasonal Incidence of aphid (*Aphis gossypii* Glove.) Infesting tomato (*Lycopersicon esculentum* L.) and their management by using botanical pesticides. *International Journal of Advances in Science Engineering and Tecnology.* **5**(3, Spl. Issue-1):14-17. ISSN-2321-9009.

Ghosh, S.K. (2019). Climate impact on red spider mite (*Tetranychus* sp. Koch) infesting eggplant (*Solanum melongena* L.) and their management using plant extracts. *Journal of Entomological Research.* **43** (3): 345-350. ISSN-0378-9519.

Laskar,N. and Ghosh, S, K. (2005). Field evaluation of tomato cultivars against serpentine leaf -miner *Liriomyza trifolli* Burg. *Journal of Applied Zoology Research.* **16**(1): 1-2.

 Ramzan, M., Singh. D., Singh, G. and Bhalla, J.S. (1990). Comparative development and seasonal abundance of hadda, Henosepilachna vigintioctopunctata (Fabr.) on some solanaceous host plants. J. Res. BAU. **27**(2): 253-262.

Subba, B., Ghosh, S.K., Ravikumar, K. and Cheetri, B. (2014). Seasonal incidence of Flea beetle (*Phyllotreta Spp*.) Infesting tomato (*Lycopersicon esculentum* L.) and their sustainable management.*The Ecoscan***6**: 175-180.

Subba, B., Ghosh, S.K., Banerjee, D. and Jasudasu, G.S. (2015). Seasonal incidence of Jassid Infesting tomato (*Lycopersicon esculentum* L.) and their sustainable management .*Annals of Plant and Soil Research***17**: 19-22 Special Issue).

Subba, B. and Ghosh, S.K. (2016). Population dynamics of Thrips (*Thrips tabaci* L.) Infesting tomato (*Lycopersicon esculentum* L.) and their sustainable management. *International J. Agriculture Sciences and Reswarch (IJASR)* ***6*** (3): 473-480.

Subba, B., Pal, S., Mandal,T. and Ghosh, S.K. (2017). Population dynamics of white fly (*Bemisia tabaci* Genn.) Infesting tomato (*Lycopersicon esculentum* L.) and their sustainable management using bio-pesticides. *Journal of Entomology and Zoology studies.(JEZS)* ***5***(3): 879-883.

Subramanian, K.S and Praghadeesh, M. (2012). Nanotechnology Applications in Plant Health Management. *InternationalConference on Plant Health Management for Food Security*, Hyderabad, 28-30 November, 2012.

Subramanian, K.S. and Tarafdar, J. C. (2011). Prospects of nanotechnology in Indian farming.*Indian Journal of Agricultural Sciences*.**81**(10): 887-893.

Thakoor, P., Ghosh, S.K., Nihal, R. and Ramya Sri, N. (2019). Effect of abiotic factors on seasonal incidence and bio-efficacy of some newer insecticides against aphid (*Aphis gossypii*) in tomato (*Abelmoschus esculentus*). *Journal of Entomology and Zoology studies.(JEZS)* ***7***(3): 513-516.