

Prospect of Nano Technology in Applied Agriculture

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ABSTRACT

Nanotechnology is an important study of multi-research and technology. It creates a large utility in many fields viz. agrochemical including insecticides, acaricides, fungicides etc; pharmaceuticals, electronics and agriculture. The utility and beneficial activity of nanotechnology is many. These may be integrated control of pests through the use of nano-material based pesticides. Integrated pest management (IPM) utilized in agri-Horti are not sufficient for pest control. The use of synthetic pesticides has adverse function on living beings, including human health. It also has a bad effect on soil property. So, nanotechnology may render green and effective alternatives for control of pests in agri-horti without any harmful effect on earth. This system may be focused on nano-materials in pest control as recent applications of nano-technology. The benefits in science and technology in the last few years were made in many areas of pesticide usage. It comprises the development of more efficient and non-persistent agro-chemicals and a new path of application that comprises controlled release formulation (CRF). The benefits may be directed towards the successful application of these formulations on crops. It is helpful for the reduction of environmental pollution. In that line, new types of chemicals are developed. Nanomaterials should be evaluated, so that this high technology does not meet the same apprehensions and bottle-neck as faced by GM (genetically modified) crops.

Key words : Nano pheromones, Nano encapsulation, Nano particles, Smart delivery, Precision farming

Introduction :

Insects are found in all possible environments throughout the globe. Their activity is large because of many important evolutionary matters such as legs, wings, exoskeleton, higher reproductive potentiality, habit diversification, weathering- resistant eggs etc.

Besides, several pests act as vectors of many diseases. Several insects damaged

crops and wood structures causing health and economic problems. To control insect pests and retain the losses made by insects in the agricultural field, toxic chemical materials are used for killing or inhibit their physiological activities like reproduction and behavioral activities like feedings.

In north east India major vegetables like brinjal, lady's finger, cabbage, chilli, pointed gourd, cauliflower etc are grown

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commercially but insect and mite pests 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 hills of the Himalaya so called Terai region of India, fruit and shoot borer was recorded very active in hot and rainy season, specifically during April-September and made about 50-80 % damage to fruits. Hadda/ spotted beetle (*Epilachne* spp.), aphid (*Aphis* spp.), jassid (*Amrasca* spp.), thrips (*Thrips* spp.), red mite (*Tetranychus* spp.) and white fly (*Bemisia* spp.) are important pests of eggplant that causes heavy damage (Ghosh, 1999). The 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 temp. ranging 24-31°C and RH 58-75% at field condition (Ramzan *et al.*, 1990; Ghosh and Senapati, 2001b.). Important pests causing damage to tomato crop are aphid (*Aphis* spp.), whitefly (*Bemesia* spp.), leaf miner *Lyriomyza* spp.), thrips (*Thrips* spp.), Jassid (*Empoasca* spp.), 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). The important pest of ladysfinger are aphid (*Aphis* spp.), Iassid (*Amrasca* spp.), whitefly (*Bemisia* spp.), different species of flee beetle and red spider mite (*Tetranychus* spp.) (Ghosh *et al.*, 2009 a; Ghosh *et al.*, 2009 b; Das *et al.*, 2010; Ghosh, 2013; Ghosh, *et al.*, 2013). Ghosh and Senapati (2002) reported that neem (Azadiractin) based pesticide is

very effective against epilachna beetles on vegetable crops recording about 70% controls. Dicofol treatment resulted better management of mite pest population on brinjal/eggplant crop (about 80 % suppression), followed by formulation mixture of phyto-chemicals, azadiractin and 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* spp.) of lady'sfinger.

For controlling the pest farmers use large amount of pesticides and so the cost of cultivation becomes very high. There is the possibility to produce nano-particle of 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.

Nano Technology :

The term “Nano” is derived from a Greek word which means “dwarf” (Bhattacharyya *et al.*, 2010). Technically the terms, “nano” means 10^{-9} , of any material. Example may be cited as, a particle may be 100 nm in size. In general, term nano-technology emerged from the use of nanometer size particles (size from 1 to 100 nm).

“Nano- technology may be self-assembly of particular atoms, or molecular clusters to form devices having new different properties.” Term nano-

technology may be used as materials size ranging of 0.1 to 100 nanometers. The materials may display many characteristics. These differences may be physical strength, electrical conductance, chemical reactivity, magnetic properties and optical properties.

Nanotechnology is potentially used in different cases and its benefits are many. These benefits comprise agri-horticultural production enhancement including nano-porous zeolites for slow release and an efficient dose of agro-inputs. It is also used as nano-capsules for weedicides supply and pest control and nano-sensors for pest and disease identification. Nano-technology has taken places of modern technologies in modern science. Nano-particles contain distinct physical, biological and chemical characteristics linking with atomic strength.

Approaches to obtain nano-materials :

There are two main approaches for getting nano- materials.

- **Self-assembly and bottom up approach :** Macro-size with a complex system is built with combination of a simple level of atomic components, principles of molecular recognition.

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

- **Top down approach :** In this system large chunks are broken into materials physically or chemically into nano objects by cutting/grinding

E.g. Mechanical grinding and Erosion

Nano technology application in agriculture :

Among the development of modern science, nanotechnology may be

recognized as a rapid evolving land which has potentiality to revolutionise both agri-Horti and food technology. The Indian Government has taken different steps 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) :

- a. **Nanofertilizer** for balanced crop nutrition and application in the field.
- b. **Effective weed control** using encapsulated herbicides and application.
- c. **Enhancing seed emergence** using nano- polymers.
- d. **Bio-sensors** for detection of pesticides, nutrients, and contaminating materials.
- e. **Smart delivery systems** for controlling matters timely, spatial targeted and effective supply of nutrients and other chemicals.
- f. **Precision farming** using autonomous sensors to monitor soil condition plant health and crop growth.
- g. **Nano biotechnology** 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 applied for :

1. Early detection of insect pest, mite pest and other pest, diseases, and nutrient deficiency in the field and plant health.
2. Nano pheromones with a sustained release of semiochemicals
3. Nano – encapsulation of plant nutrients, herbicides and pesticides
4. Nano – particles for control of pests and diseases
5. A mechanism developed for proper utilization of bio-control agent
6. A smart delivery mechanism of different types of agriculture inputs (Subramanian and Praghadeesh, 2012)

Early detection of pests, diseases, and nutrient deficiencies Biosensors :

Nanotechnology plays a vital role in production of bio-sensors. Nanomaterials may improve sensitivity and other aspects of bio-sensors. 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. The term nano-biosensor refers to those whose properties are modulated because of a nano- scale in which they are made. They have high sensitivity, high selectivity, reliability and rapidity.

Electronic nose (E-nose) :

E-nose may be called a device which has mimicry of operating of human nose having detection power of an array of gases. The device consists of many gas sensors

for detecting many types of odors. The vital purpose of E-nose is for identifying the odour, estimating the concentration of the odorant and find different values of the odour. E-nose comprises a gas sensor comprised of Nanoparticles (zinc oxide nano-wires) and its resistance changes if certain gas passes through it. The change in resistant power generates a change in a signal of electric which forms the print of gas detection. Nano-particles developed an uncontaminated area of the surface for better gas absorption. 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 a sustained release of semio-chemicals :

The important method of IPM has used the pheromone trap for sustainable pest management. Nano-science 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 activity of pheromones. It increases their shelf-life through entrapped activity having favourable host matrix. Thus, nanotechnology helps to develop practically simple, and a lower cost green chemical (eco-friendly) system of pest control. Thus, it acts a vital role in plant protection, longer persistent function, better bio-efficacy and safe 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 in better pest control of *B. dorsalis* with baiting traps. Pest is killed by trapping following this technology :

Examples of enhancement of shelf-life of ME in the nano-gel

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 fly may be attracted to the plate-A and to the plate-C all the period, and don't go to the plate-B that held gelator in toluene. This means that this pheromone is bio-active in the nano-gel and is helpful for catching pests, though the material 1 is inactive to fruit fly. The catching of pests is better with time both the plates-A and plates-C.

The plates are kept at room temp. (About 30°C) and after 21 days, are kept again in the same guava garden. At the time, fruit flies are attracted to plate-A only that had the nano-gel and not to the plate-B or plate-C for all time of reading.

Development of a nano-matrix for delivery of the pheromone (ethyl 4 methyl octanate) of coconut rhinoceros beetle, *Oryctes rhinoceros*.

- Subramanian and Praghadeesh (2012)

- An aggregation pheromone (ethyl 4 methyl octanate) loaded in polymer membrane dispensers may be used for mass trapping of rhinoceros beetles.

But these have a high rate of release of 10-30 mg/day than nano.

- Nano-porous particles are a good carrier/dispenser for materials with a volatile signal having controlled spatio-temporal releasing rate. Nano-dispensar made of meso-porous sieves, with pored channels, was formed for loading pheromone of rhinoceros beetle.
- Release rate of entrapped pheromone in nanomatrix was slower compared to commercial lures having a polymer membrane.
- Field test of pheromone kept in nano-matrix 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 nano-matrix 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.

I. Nano emulsion :

Stability of nano-emulsions is very high. These have little coalescence of pesticide molecules, non-sedimentation or creaming. These consist of lipid or polymeric vesicles or particles, ranging of 20-200 nano-meter size. 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 prolonged 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.

II. Nano suspension :

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

Advantages :

- higher in a surface area.
- Higher Solubility.
- Induction systemic activity is because of smaller in material size. They may be very active against insect pests having sucking type of the mouth parts.
- Toxicity is lower because of removal of organic solvents.

III. 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 material in a shell. The chemical is protected by the shell from damage by external materials and helps to develop its solubility & penetrating activity through tissue.

Nano formulations of insecticides going to develop

Formulation	Name of the Product	Manufacturer	Advantages
<i>Nano-emulsion</i>	Oil of the citronella	National Sc. & Technology Development Agency, Thailand	Protecting mosquito for long
	Triazophos	College of Chemistry & Environmental Sc., China	In acidic and neutral media it is stable and hydrolyzing easily in basic solution.
<i>Nano-suspension</i>	Novaluron	Makhteshim Chemical works Ltd., Israel	Penetrating power is increased through cuticular cells
	Beta-Cypermethrin	College of Chemistry & Molecular Science., Wuhan University, China	Dissolution rate is very fast

Formulation	Name of the Product	Manufacturer	Advantages
	Nanomaterials having PEG coated with Essential Oil of Garlic	Huazhong Agricultural University, China	The active components are released slowly to control <i>Tribolium castaneum</i>
Nano-particles	Bifenthrin	Princeton University, USA	Efficiency is very high, uniform coverage for active materials and lower exposure to working persons
	Sugar coated novel particle (Bio-pesticides)	The University of Queensland, Australia.	Active ingredients of the particles are protected from weathering and photo degradation
Nano-capsules	Nano-capsules of Parathyroid	Hong Kong Polytech. University	Repelling activity of Mosquito and better retention of insecticide
	Nano-Imidacloprid	Dept. of Life & Sciences, China	Releasing period is longer
	Karate® ZEON lambda-cyhalothrin	Syngenta	Releasing activity is quick; improve residual activity is improved, protecting from UV light.
	Demand 2.5CS (γ-cyhalothrin)	Syngenta	Knock down activity is very quick. Residual activity is good
	ICONET (γ-cyhalothrin) 2.5CS	Syngenta	Prolonged activity, mosquito repellency

Nano encapsulation :

Nano encapsulation may be designated as a slow releasing of pesticide molecules. By this process, chemical pesticide is released slowly by efficient manner to the certain host of pests and disease

management. Releasing mechanism comprised dissolution, bio-degradation, diffusion and osmosis pressure containing certain pH. Encapsulated citronella oil nano-emulsion may be formed by high-pressure homogenization of 2.5% surfactant and

100% glycerol, to produce droplets with proper stability which increases the retention of oil and releasing slowly. The rate of releasing depends on protection period; a decreasing in a rate of releasing may prolong mosquito protection time. By utilizing this method, nano-pesticides, nano-fungicides and nano-herbicides may be used in agriculture with efficient manner.

Pests of cotton, rice, peanuts and soybeans are controlled by another encapsulated product from Syngenta, marketed as KARATE ZEON. It is a quick releasing micro-encapsulated product contained active compound lambda – cyalothrin that breaks upon on contact with leaves.

Syngenta also holds a patent on gutbuster, an encapsulated product which breaks upon releasing its contents only in contact with an alkaline situation, viz. the stomach of specific pest. 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 material which blocks the insect gamma – amino-butyric acidic receptor. The neuro-transmission faces problems of photo-inactivation during the time of field applications. The nano-sphere formulation showed improved penetration through the plant because of their smaller size. (Boehm *et al.*, 2003).

Pesticides having short half-life period viz abamectin (six hour), the insect chloride channel inhibitor blocks neuro-transmission, arised problems of UV

inactivation on the fields. Porous hollow silica NPs with a shell thickness of ~ 15 nano-meters and a pore diameter of 4-5 nano-meter were reported to protect abarmectin from a UV degradation and allowed its slow releasing. Slow releasing of encapsuled abarmectin with the NPs carrier had been observed for about thirty days (Ghormade *et al.*, 201).

Nano based delivery of bio-pesticides :

Phyto-chemicals (plant based formulation) such as essential oils face problems of chemical instability in a presence of air, light, moisture and high temp. These climatic factors have influence to high evaporation and degradation of many active materials. Rapid evaporation and degradation may be prevented by adding of essential oils into a checked releasing nano- formulation, and thus develops stability and maintains min. effective doses.

Insecticide activity of extracted essential oil from *Allium sativum* (garlic) was examined against an adult pest, *Tribolium castaneum*. Due to slow releasing of pesticides, 80% of the pesticides remained after a five month in comparison to free garlic essential oil (11%).

Nano particles :

Definition of nano particles are natural or incidental or manufactural compounds having particles, for fifty per cent or above of the particles, one or more external dimensions in size ranging from 1 – 100 nano-meter. Nano particles are good for applicable in protecting crops from pest because of its size and quality, higher surface to volume ratio, and unique optical properties.

Nano-particles and its entomological and toxicological function against *Sitophilus oryzae* L.-Debnath et al. (2011) :

Considering the resistant and residue toxicity problem against pest and to storage pesticides is led to evolve new and better strategies for protection of products in storage. Diatomaceous earths (DE s), One such alternative composed mainly of amorphous silica. The past formulation of DE was not vastly accepted as they have bad effects on the grains with bulk density. *Sitophilus oryzae* is has resistant problem to phosphine and generally used pesticides like pyrethroids, Silica nano particles (SNPs) are used in this study, which is claimed to be relatively non hazardous.

There is a declaration from the part of the USDA that non-crystalline silica is safe.

Hydrophilic SNPs made and modified particles revealed enough insecticide property at 1g/kg dose or more at the first day. After day four, more than ninety per cent *S. oryzae* is killed when hydrophilic SNPs (both types) was given in a dose of 1g/kg. Bulk sized silica even at the highest dose caused only 34% insect mortality. So custom made (15-20nano-meter) hydrophilic SNPs & 20-30 nano-meter modified particles SNPs found equally active on *S. oryzae* at a significant level of 95%. SNPs was found having no adverse effect on crop health. Moreover, there is enhancement of rigidity and strength of crops.

Results of three dosages treatment after seven days with bulk and nano silica against *Sitophilus oryzae* adults ($\pm$ S.E.), mean mortality

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

Nano silica found better in action than bulk silica because it has more exposure of surfaces which had interaction with the cuticles surface of an insect body. Due to sorption and abrasion, damage occurs to the insect's protective wax coat on the cuticle. The insect starts of losing water through desiccation and die. New

infestation of insects was not seen in SNP applied rice in storage even two months after application. The removal of nano-cide may be done by a general milling system.

Smart delivery mechanism :

In medical treatment, nanodevices were first applied as a system of delivery

for particular targets in living organisms. The similar type of application may be used in plants in a broader range to overcome infections. Nanoparticles when applied as agrochemicals may decrease the other plant tissue damage. It may decrease the amount of pesticides or other chemicals releasing to the environment.

Use of Bio-degradable nano-fibres as a carrier for slow release of the pesticides :

Controlled delivery system is defined as controlled release of necessary and sufficient amounts of pesticides for a certain period. It is also used to gain full bio-efficacy and to decrease the bad effects. Nano-fibres incorporated with pesticides

function as an effective controlled delivery technique.

Imidacloprid, and tebuconazole are designated as insecticide and fungicide respectively were mixed into poly (lactic-co-glycolic acid) [PLGA] bio-polymer with a lactic acid a ratio of 85:15 and nanofibres are produced by electro-spinning processes. The size of nanofibres ranged from 130 nm to 250 nm in dia. By virtue of their nano-scale diameter and a large surface area, electro-spunfibres 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	Risks involved
Silica nanoparticles , Carbon nanomaterials	Blood circulatory problem, granulomas, fibrosis
Silver, Carbon, Gold nanomaterials central nervous system	Dispersed into many organs including
Carbon, Quantum dots , TiO_2 nanoparticles	Penetration into the skin
MnO TiO_2 , carbon nanoparticles epithelium olfactory neurons	Enter into brain through nasal
TiO_2 , Al_2O_3 , Carbon black, CO , Ni	Toxicity is more than a micron sized particles

- ZnO nanoparticles found to be toxic to gram negative and gram positive bacteria, *Escherichia coli* and *Staphylococcus aureus*.
- A single high oral dose of nano TiO_2 produced significant lesions in kidney and liver of female mice.
- Nano TiO_2 may have toxicity to algae and water fleas, after exposure to UV light.
- 15 nano-meter Ag nano particles found to be toxic to mouse germ line stem cells *in vitro*.

- 50 & 70 nano-meter SiO₂ particles given into cell nucleus produced aberrant protein formation and hampered cell growth, in vitro.

What are the solutions?

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

Conclusion :

The nano-technology is well established in the medical sciences which made breakthroughs in finding solution to serious human diseases without associated any side effects. In agriculture, this technology is at nascent stage. Promising results are obtained from using of nano materials for a supply 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.

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 Research* **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. Incidence 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 biguttula* Ishida) on okra in terai agro-ecology of West Bengal. *Journal of Applied Zoology Research* **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 Entomology* **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. 2009a. Bio-efficacy of microbial formulation against red spider mite (*Tetranychus urticae* Koch.) infesting ladyfinger (*Abelmoschus esculentus* L.) *Green Farming* **2**(10):685-688.
- Ghosh, S.K., Mahapatra, G.S.S. and Chakraborty, G. 2009b. 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 ladyfinger (*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 Journal of Agriculture Sciences and Research (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. *International Conference 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.