Review Article

Application of Nanotechnology for Insect Pests Management: A Review

Muhammad Shahid[1]*, Unsar Naeem-Ullah[1], Waheed S. Khan[2], Shafqat Saeed[1] and Kashif Razzaq[3]

[1]Institute of Plant Protection, MNS-University of Agriculture, Multan, Punjab, Pakistan; [2]Nanobiotechnology Group, National Institute for Biotechnology and Genetic Engineering (NIBGE), Jhang Road Faisalabad, Punjab, Pakistan; [3]Department of Horticulture, MNS-University of Agriculture, Multan, Punjab, Pakistan.

Abstract | The nature acts like a large "bio-laboratory" comprising of plants, algae, fungi, yeast, etc. which are consists of wide array of biomolecules. There is various size and shapes of nanoparticles to be synthesized by using the naturally occurring biomolecules. These biomolecules acting as a driving force for the designing of greener, safe and environmentally benign protocols for the synthesis of nanoparticles. Insect pests are main density dependent factors that deteriorate the quality and production of various crops i.e. vegetables, fruits, ornamental and field crops. In past decade, these insect pests had been controlled by the application of synthetic insecticides but due to the injurious application of these insecticides causes the development of resistance, environmental pollution, pest resurgence and unwanted effects on humans, animals and beneficial fauna. The pesticides residues remain in the different parts of the crops and cause the lethal effects on human health. Many countries in the world switched from chemical based agriculture to green based agriculture that are ecologically reliable, socially acceptable and economically sound. In current scenario, the nanotechnology has revolutionized the agriculture with the greatest potential of nano based insecticides for the insect pest management. The physical and chemical approaches are most widely used for the synthesis of nanoparticles but actually they are detrimental for the environment and human health. The emphasis of this review article is to critic the potential of nanotechnology for insect pest management. Various metals i.e. Zinc (Zn), Titanium (Ti), Silver (Ag) and Zirconium (Zr) are used for nanoparticles synthesis by using green synthesis approach. The present review is devoted to the possibility of metal nanoparticle synthesis using different biological materials i.e. polymer, bacteria, viruses, plant extracts, fungi, and protein. This review article climaxes the latest mileposts accomplished for the production and imminent perspective of nanoparticles for the controlling of insect pests.

Received | September 28, 2020; **Accepted** | November 10, 2020; **Published** | March 02, 2021
***Correspondence** | Muhammad Shahid, Institute of Plant Protection, MNS-University of Agriculture, Multan, Punjab, Pakistan; **Email:** shahid.css3322@gmail.com
Citation | Shahid, M., Naeem-Ullah, U., Khan, W.S., Saeed, S. and Razzaq, K., 2021. Application of nanotechnology for insect pests management: A review. *Journal of Innovative Sciences,* 7(1): 28-39.
DOI | http://dx.doi.org/10.17582/journal.jis/2021/7.1.28.39
Keywords | Nanoparticles, Insecticides, Plant extracts, Insect pests, Pollution, Biomolecules

1. Introduction

In 2050, the scientist Friedrich predicted that, the worldwide food production will be about 70% but the expected population will be increased up to 9.2 billion. By adapting sustainable, abundant, safe and innovative supply techniques we can achieve the high quality production of various crops. The various methods of cultivation are very helpful to grow the crops in those places where they could not survive. Different plant specific protection measures i.e. pesticide and herbicides tolerant varieties and nutritionally enhanced traits are helpful for adapting bio-intensive integrated disease and pest management (Friedrich, 2015).

The term "Nano" is consequent from Greek word that means "dwarf" and in simple it is a science of small. "Nano" can be defined as the one billionth of something or 10^{-9}. Naturally the nanotechnology means the particles which are used in a nanometer size (1-100 nm in size) (Bhattacharyya *et al*., 2010). In the last decade, the nanotechnology has evolved many innovative materials in the forthcoming application. Environmental cleanup is a major problem that could be solved by application of nanoparticles that is a biggest challenge in society (Chinnamuthu and Boopathi, 2009). Insect-pests are the major density dependent factors that deteriorate the quality of crops and it is also controlled by application of synthetic insecticides, which provides an impetus for assessment into some bio-rational and ecofriendly substitutes (Subashini *et al*., 2004).

The modernized and excellent innovations have been done by nanotechnology in different fields of science such as agriculture, engineering, medicine, environmental science, food processing, biotechnology and analytical chemistry. But their use is at initial stage for the protection of various crops against insect pests (Resham *et al*., 2015). Nanomaterials have potential to combat drastic effect of insect pests that destroy the crops (Khot *et al*., 2012). These materials have been used as sensors, medical devices, catalytic agents, coatings as pesticides, conductors and semi-conductors (Jordan, 2010).

The global world has been substituting from synthetic chemical based agriculture towards the organic agriculture by application of nanoparticles impregnated biopesticides. These types of biopesticides have capability for an efficient suppression of pest population (Bhattacharyya *et al*., 2010; De *et al*., 2014). Leguminaceae (*Pongamia pinnata* (L.) Pierre.), Meliaceae (*Azadirachta indica* A. Juss), Schultz Bip., *Chrysanthemum cinerariifolium* (Trev.), Compositae (*Tanacetum cinerariifolium* (Trev.) Annonaceae (*Asimina triloba*, *Annona muricata* and *Annona squamosa*), and *Pyrethrum cinerariifolium* Trev. These plants have potential for synthesis of various nanoparticles.

1.1 Losses of crops and its associates

The production of the crops decreasing day by day due to the severe attacks of pests like weeds, insect pests, mites, rodents, birds, mollusks and phytopathogens including fungi, virus and bacteria. All these organisms are considered as the photosynthetic rate reducer, tissue consumer and leaves senescence accelerator. The sucking and chewing pests reduces the crop yield in a drastic way. The necrotrophic pathogens diminishes the plant quality by transmitting the viruses and lowest the chlorophyll contents. The crop rotation, resistant varieties, rouging, biological and chemical control are some of integrated management tactics that helpful for suppression of pest population. The entomotoxic potential of biosynthesized nanoparticles has led to the need of the time to protect the environment from hazardous materials and for the suppression of pest population.

1.2 Insect pests threat to crops

The insect pests with varied number of the species are present in wide array of the environment. There is large number of insect pests that acts as vectors by transmitting the multiple diseases among the various plant species. The economy and crop yield diminish due to harshly attack of pests and per annum the billion rupees of losses has been done (Ramya *et al*., 2008). The insect pests are controlled by the application of synthetic insecticides but due to resistance problems each year billion rupees losses (Ragaei and Sabry, 2014). Globally, the *Helicoverpa armigera* cause the severe damage to the crops cotton, peanut, corn, chickpea, tomato and sorghum in field conditions (Ragaei and Sabry, 2014). This pest prevailed mostly in Africa, Asia, Oceania, South America and Europe (Sullivan and Molet, 2007). About 150 species of insect pests that attacks and deteriorate the quality and production of crops at various life stages (Sullivan and Molet, 2007; Gandhi and Nimboodiri, 2009). This has made an advent for a researcher to over these problems by the application of innovative technologies.

1.3 Why nanotechnology based agriculture

The safest and ecofriendly tool to improve the food process, more agriculture production, enhance nutrition value, better flavor and crop protection has been done by using biotechnology. The toxic materials, genetically engineered crops, viruses, bacteria and insecticidal resistance have been spreading through food chain systems (Wieczorek, 2003). The nanotechnology helps to combat on these issues and revolutionized the food, textile, energy and communication technology. The global population increased day by day and more food consumed by the peoples. Research scientists are trying to overcome these problems by introducing the novel approaches to suppress the pest infestations in order to produce more agriculture products. The nanoparticles that have been synthesized by using biological materials play significant role in the preparation of pesticides formulations, water filtration and crop protection (Barik *et al*., 2008; Prasad *et al*., 2014).

In the modern era of science, the biotechnology has been well thought out as a harmless agricultural tool to strengthen the crop protection, modified food process, packaging materials, supply more agricultural produces, improve flavor and better nutritional value. This technology is very helpful by the insertion of engineered genes into the native plants to increase the toxic lethality by disrupting the internal systems of the pests (Wieczorek, 2003). So, it is very necessary for the scientists to combat on these problems by adopting the inventive technology.

In this arena of science, the nanotechnology has revolutionized the many disciplines such as materials, information technology, health care, energy sectors, communication and too much application in the field of agriculture. The population pressure in the worldwide is a major problem that has been demanded the increased supply of food by the controlling of harmful pests by the application of nanoparticles and to increase the quality and production of the crops. The substantial role of biological and chemical nanomaterials is to be increased the plants protection, remediation of harmful pesticides and synthesis of pesticides formulations (Barik *et al*., 2008). The nanotechnology plays an important role for the development of organic farming, disease control and efficient delivery of fertilizers, pesticides and other agrochemicals (Prasad *et al*., 2014).

1.4 Global demand of biopesticides

In the modern biosphere, the minimum amount to be invested for the production of ecologically reliable and socially acceptable pesticide formulations to the efficient management of insect pests. The demand of Biopesticides formulations as a form of product consumption by farmers increased gradually. In 2013-2014, it was perceived that the global consumptions of synthetic pesticides and Biopesticides were amplified from $54.8 to $61.8 billion while in 2019 it was expanded up to $83.7 billion (Lehr, 2014). In 2019, the global sale of biopesticides was up to USD 6.9 billion. The demand of biopesticides was 20% in Asia-Pacific region while 40% of market demanded in the North America. Globally, there are many countries that rely on biopesticides for ecofriendly management of harmful insect pests for the provision of food security (Patent mall SDN BHD, Kuala Lumpur, Malaysia).

1.5 Chemical based pest management (Traditional approach)

In the last decade, most of the synthetic chemicals are present in online source, local pest store such as Amazon and there were several exporters, dealers and manufactures. The Sulphur element such as phosphate fertilizers, fungicides, sulfuric acid and insecticides was utilized in early times. The general efficient chemicals including fipronil, permethrin, bifenthrin, pyrethrum, boric acid and abamectin were applied against insect pests apart from the Sulphur. The chemicals are categorized on the origin of structures of chemicals e.g. organochlorines, neonicotinoids, pyrethroids, organophosphates and carbamates. The insecticides available for the management of insect pests are bioresmethrin, carbaryl, acephate, azadirachtin, fenitrothion, malathion, dichlorvos, pirimiphos methyl and pyrethrum. The repeated applications of same mode of action of insecticides cause the development of resistance, pest resurgence and hazardous effect on environment and health (Kamaraj *et al*., 2008). The application of conventional insecticides were failed for the management of pests e.g. phytochemicals due to the development of resistance. An experiment was conducted to evaluate the toxic potential of nanoparticles based novaluron sized 30-100 nm in size against larvae of *Spodoptera littoralis* and the chemicals remain as byproduct were not used for the synthesis (Elek *et al*., 2010).

1.6 Biological based pest management (Old approach)

The metabolites present in various plants such as terpenoids, alkaloids, phenolic compounds, glycosides, flavonoids, polyphenols and tannins have been used as biopesticides which have an advantage of being ecofriendly for humans and animals (Ge and Ding, 1996). There are several medicinal plant extracts that have optimistic effect on *Helicoverpa armigera* and mosquitoes. There are some plants that have pesticidal and larvicidal toxic effect on insect pests such as *Gnidia glauca*, *Toddalia asiatica* (Sundararajan and Kumuthakalavalli, 2001), *Acorus calamus*, *Annona squamosa*, *Vitex negundo* (Murugan *et al*., 1998), neem extract (Chopra *et al*., 1994), *Calotropis procera* (Lall *et al*., 2014) and *Argimone maxicana* (Malarvannan *et al*., 2008). An experiment was conducted to monitor the toxic effect of neem seed kernel extract that shows highest percent infestation (30.08%) as compared to tobacco leaves extract (26.68%) (Rahman *et al*., 2014). The neem seed extract poisonousness was used to evaluate the ovicidal, hatching performance, nymphal duration and antifeedants on tea mosquito bug under laboratory conditions (Dutta *et al*., 2013). There are different plant parts such as fruit, leaves, stem and root extracts used to check the efficiency against insect pests. The bark extract of *Ficus racemosa* were assessed against larvae of Japanese encephalitis vectors, filariasis vector and *Culex quinquefasciatus* (Velayutham *et al*., 2013).

1.7 Nano-based pest management (Innovative approach)

The nanotechnology has been proposed in wide array of field and to create the several formulations and several applications in many meadows likewise biomass, food, nutrition, paint, sensing technology, paper, fertilizer industry, plant protections and in agrochemical industries (Sadowski, 2010). The formulations of nano based pesticides such as ZnO, Cu, Ag and SiO_2 nanoparticles show broad spectrum, reducing water and remedies the environmental pollution as compared to the conventional insecticides (Chhipa, 2017). The zinc which is an essential nutrient element helps in plant growth and development and has toxic effect on insect pests. The silver has great potential that is used in the field of medicine, living organisms, pest control and plant management with better efficiency and activity by the green method to use as microbial, fungal, larvicidal, pesticidal, antibacterial and anti-viral activity (Chopra *et al*., 1994; Kharissova *et al*., 2009; Gao *et al*., 2014; Chhipa, 2017). The ZnO nanoparticles antifungal activity was checked against plant pathogen *Fusarium graminearum* (Dimkpa *et al*., 2013). The stability, smaller particles size and ecofriendly byproducts are the characteristics of metal nanoparticles (Iravani, 2011). The best possible alternative management techniques for the insect pests control are nanoformulations.

1.8 Natural occurrence of nanoparticles in insects

The naturally occurring nanostructures are enormous source of precise produces but these are abandoned by some scientists (Watson and Watson, 2004; Bhattacharyya and Debnath, 2008; Ehrlich *et al*., 2008). In cicada *Psaltoda claripennis* Ashton and in the termites of the family Rhinotermitidae the hexagonal shape of structures is present in these insect pests which are examined by atomic force microscopy (AFM) (Zhang and Liu, 2006). The top of the structure of these nanoparticles are flat surface to the size range about 150-350 nm and have a tendency to be round shaped with the almost size range from 200-1000 nm. In the wings of insects, the nanoparticles play an important role in aerodynamic effectiveness. The insects have temperature dependent ferromagnetic resonance and the magnetic material present in various body parts of the insects like in social insects and ants (Nowack and Bucheli, 2007). By alterations in the surrounding of magnetic field the behavior of the higher animals also affected. The honey bees, ant *Formica rufa* Linnaeus and *Solenopsis invicta* Buren used the geomagnetic field information for foraging, homing and orientation (Slowik *et al*., 1997; Binhi, 2004). The magnetic signals in ants species has been recognized by using magnetite nanopartilces which is observed by electron microscope. In the abdomen of workers *S. invicta* the ferric ions has also been observed (Abracado *et al*., 2005). Magnetic elements have been detected in the stingless bees *Apis mellifera* Linnaeus, *Pachycondyla marginata* Roger, *Schwarziana quadripunctata* Lepeletier (Wajnberg *et al*., 2000; El-Jaick *et al*., 2007; Sahoo, 2014). To detect the natural magnetism in the fire ant (*S. invicta*) of workers and queens by using the Magnetic resonance imaging (MRI). The Bright color components of butterflies and compound eyes of insects are due to the presence of nanoparticles.

1.9 Biosynthesis of nanoparticles

There are various approaches used for the synthesis of nanoparticles including physically, biologically and chemically. The chemicals have adverse effects on humans and environment and have been absorbed on the surface. The most economical, socially acceptable and ecologically reliable alternatives to physical and chemical methods are biological methods. Green synthesis of nanoparticles is done by using enzymes (Willner *et al*., 2006), green plant materials (Shankar *et al*., 2004; Ahmad *et al*., 2011), microorganisms (Klaus *et al*., 1999; Konishi *et al*., 2007) and fungus

(Vigneshwaran *et al.*, 2007). The silver nanoparticles are most widely used in many arenas of science (Armendariz *et al.*, 2002; Kyriacou *et al.*, 2004; Kim *et al.*, 2010). The nanoparticles synthesized with help of viruses, bacteria, fungi and plant extracts that are safe, cost effective, ecofriendly, biocompatible and green approach (Abdul *et al.*, 2014).

The chemicals are also used for the production of nanoparticles. There is a chemical bond present between active compounds and coating matrix such as polymer. The insecticide molecule can bind initially to the side-chain of one monomer and then the polymerization reaction takes place or the polymerization occurs first and only after that, the biocide binds to the side chain (Wilkins, 2004). The nanoparticles were synthesized by using gold, copper, silver and other metallic oxides that has been proven to be effective against various insect pests (Singh, 2012).

1. 10 Synthesis of nanoparticles by bacteria

Silver nanoparticles: The extracellular and intracellular formation of Ag NPs has been explored by using various bacteria e.g. *Salmonells typlus, Pseudomonas aeruginosa, Pseudomonas stulzeri, Escherichia coli, Vibrio cholera* and *Staphylococcus currens* (Lengke *et al.*, 2007). The metal ions reduce to metals with the help of microbes. The photoautotrophic cyanobacterium, *Plectonema boryanum* had been used for extracellular formation of silver NPs (Lengke *et al.*, 2007). The formation of silver nanoparticles in the range of 50 nm in size has been done with *Bacillus licheniformis* (Kalishwaralal *et al.*, 2008). The treating of aqueous silver nitrate solution with culture supernatants of altered strains of Enterobacteria such as *Klebsiella pneumonia* is recently the most rapid method for the development of silver nanoparticles (Shahverdi *et al.*, 2007; Mokhtari *et al.*, 2009).

Zinc oxide nanoparticles: Bacteria are used for formations of nanoparticles but it has numerous drawbacks alike selection of microbes is a laborious procedure. The whole process is to be required very keen observation and vigilant monitoring of culture broth. The *B. licheniformis* are very helpful for the synthesis of ZnO nanoflowers. These nanoflowers were in 40nm in width and 400nm in height (Raliya and Tarafdar, 2013). The effective bioremediation of organic waste material is also done by the application of nanoparticles. The biodegradation of hydrophobic compounds was also done by *Rhodococcus* (Otari *et al.*, 2012).

1.11 Synthesis of nanoparticles by using plant extracts

Silver Nanoparticles: The distinct technique for the green synthesis of Ag NPs is done by using the plant extracts that are cost effective, ecologically reliable and economically sound. These extracts act as stabilization and reduction of silver ions (Kulkarni and Muddapur, 2014). The protocol adapted for the nanoparticles synthesis by using the green plant materials. The plants leaves were cleaned by using the tap water and distilled water in order to remove the dust and debris materials from the surface of plants. Then take 10g of leaves and boiled in 100 ml of distilled water. The plant extracts were prepared. The $AgNO_3$ is to be added into the distilled water to make aqueous solution. The plant extracts were added drop wise into the aqueous solution of silver nitrate in order to the reduction of pure Ag (I) ions to Ag (0). This synthesized solution was monitored by the UV-Visible spectrophotometer with the regular intervals (Krishnaraj *et al.*, 2010).

Zinc oxide (ZnO) nanoparticles: The ZnO is semiconducting metal oxide that plays an important in the field of optics, biomedical systems and electronics (Gunalan *et al.*, 2012; Vanathi *et al.*, 2014; Anbuvannan *et al.*, 2015; Sundrarajan *et al.*, 2015; Patil *et al.*, 2016). It is play vital role in the arena of biomedical sciences by the applications like antidiabetic, agricultural properties, antifungal, anti- cancer, drug delivery and antibacterial, (Martiankova *et al.*, 2009; Movahedi *et al.*, 2014; Jain *et al.*, 2014; Sangani *et al.*, 2015; Hameed *et al.*, 2016). The advantages of ZnO nanoparticles are that they are safe, cost-effective and can be easily prepare (Jayaseelan *et al.*, 2012). US FDA has enlisted ZnO as GRAS (generally recognized as safe) metal oxide (Pulit-prociak *et al.*, 2016).

The various parts of plants that contain toxic metabolites are used for nanoparticles synthesis. These plants are also acting as the stabilizing and reducing agent (Nagajyothi *et al.*, 2013; Gnanajobitha *et al.*, 2013; Zong *et al.*, 2014; Nachiyar *et al.*, 2015; Ramesh *et al.*, 2015; Rajeshkumar, 2016; Xiao *et al.*, 2016). The *Trifolium pratense* flower extract was used for the synthesis of ZnO nanoparticles and these were analyzed by UV- visible spectrophotometer in order to showing the various peaks and formation of stable nanoparticles. The *Rosa canina* and *Aloe vera* extracts was used as capping and reducing agent confirmed by the FTIR studies (Dobrucka and Długaszewska, 2016).

1.12 Synthesis of nanoparticles using fungus

The extracellular formation of NPs has been done with fungus material (Azizi *et al*., 2014). The fungal strains have better tolerance and bioaccumulation property as compared to bacteria (Pati *et al*., 2014). The average size of nanoparticles was 3.8nm synthesized by using fungus was examined by the atomic force microscopy (AFM) and dynamic light scattering (DLS) was used to check the average height of nanoparticles that was about 8.56 nm in size (Hoffmann *et al*., 1995; Pavani *et al*., 2012; Shamsuzzaman *et al*., 2013). The most widely fungus species that was used for the synthesis of nanoparticles is *Aspergillus* that has mostly spherical in shape.

1.13 Nanoparticles application in sustainable way

The formation of nanoparticles has been done by using plant extracts that are safe, easy to access and cost-effective. There is broad range of phytochemicals present in different parts of plants. The nanoporus zeolites were used for the slow release of herbicides, fertilizer, irrigation and pest management. The nanosensor was used for the detection of pests in field conditions (Scrinis and Lyons, 2007). The insect repellent, pesticides and insecticides was synthesized by using nanoparticles (Owolade *et al*., 2008). The *Tribolium castaneum* was efficiently controlled by the garlic essential oils loaded with nanoparticles (Yang *et al*., 2009). It is need of the time to combat all entomological problems by the introduction of ecologically reliable and socially acceptable Biopesticides through nanotechnology.

Conclusions and Recommendations

The nanotechnology has great potential in various areas of science. In near future the pest control to be done by the application of nanotechnology that is an ecofriendly way and is to be need of the research of the day. The biological materials are cost effective for nanoparticles synthesis. This method of synthesis has great advantage over synthetic chemical insecticides due to its eco-toxicity. The current review article specifies that the prospective of nanoparticles used for the efficient suppression of pest population and probable prospects to adventure them in future.

Acknowledgements

Authors are very thankful to HEC for providing funding to Mr. Shahid under Indigenous PhD Fellowship Program Phase-II, Batch-IV.

Novelty Statement

Nanotechnology is an advanced technology used in agriculture sector particularly for insect pest management across the world as well as in Pakistan.

Author's Contribution

Muhammad Shahid wrote the introduction part of the manuscript. Unsar Naeem-Ullah format the manuscript according to journal. Waheed S. Khan review this article and gave fruitful suggestions. Kashif Razzaq and Shafqat Saeed finally examined, scrutinized and approved the manuscript for final submission by all authors.

Conflict of interest

The authors have declared no conflict of interest.

References

Abdul, H., Sivaraj, R., and Venckatesh, R., 2014. Green synthesis and characterization of zinc oxide nanoparticles from *Ocimum basilicum* L. var. *purpurascens Benth*. lamiaceae leaf extract. *Material Letter.* 131: 16–18. https://doi.org/10.1016/j.matlet.2014.05.033

Abracado, L.G., Esquivel, D.M.S., Alves, O.C., and Wajnbergo, E., 2005. Magnetic material in head, thorax, and abdomen of *Solenopsis substituta* ants: A ferromagnetic resonance study. *Journal of Magnetic Resonance,* 175(2): 309-316. https://doi.org/10.1016/j.jmr.2005.05.006

Ahmad, N., Sharma, S., Singh, V.N., Shamsi, S.F., Fatma, A., and Mehta, B.R., 2011. Biosynthesis of silver nanoparticles from *Desmodium triflorum*: a novel approach towards weed utilization, *Biotechnology Research International,* 1(8): 2011. https://doi.org/10.4061/2011/454090

Anbuvannan, M., Ramesh, M., Viruthagiri, G., Shanmugam, N., and Kannadasan, N., 2015. Synthesis, characterization and photocatalytic activity of ZnO nanoparticles prepared by biological method. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 143:

304-308. https://doi.org/10.1016/j.saa.2015.01.124

Armendariz, V., Gardea-Torresdey, J.L., Jose Yacaman, M., Gonzalez, J., Herrera, I., and Parsons, J.G., 2002. Proceedings of conference on application of waste remediation technologies to agricultural contamination of water resources, Kansas City, Mo, USA.

Azizi, S., Ahmad, M.B., Namvar, F., and Mohamad, R., 2014. Green biosynthesis and characterization of zinc oxide nanoparticles using brown marine macroalga *Sargassum muticum* aqueous extract. *Materials Letter,* 116: 275–277. https://doi.org/10.1016/j.matlet.2013.11.038

Barik, T. K., Sahu, B., and Swain, V., 2008. Nanosilica from medicine to pest control. *Parasitology Research*, 103(2): 253-258. https://doi.org/10.1007/s00436-008-0975-7

Bhattacharyya, A., and Debnath, N., 2008. *Nano particles-A futuristic approach in insect population*. In: Proceedings on UGC sponsored national seminar on recent advances in genetics and molecular biology, biotechnology and bioinformatics, 21st and 22nd November.

Bhattacharyya, A., and Debnath, N., 2008. *Nano particles-A futuristic approach in insect population*. In: Proceedings on UGC sponsored national seminar on recent advances in genetics and molecular biology, biotechnology and bioinformatics, 21st and 22nd November, 2008. Jointly organized by department of zoology and botany, Vidyasagar College, Kolkata-700006. West Bengal, Indian.

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

Binhi, V.N., 2004. *Stochastic dynamics of magnetic nanoparticles and a mechanism of biological orientation in the geomagnetic field*. arXiv preprint physics/0412158.

Chhipa, H., 2017. Nanofertilizers and nanopesticides for agriculture. *Environmental Chemistry Letters*, 15(1): 15-22. https://doi.org/10.1007/s10311-016-0600-4

Chinnamuthu, C.R., and Boopathi, P.M., 2009. Nanotechnology and agroecosystem. *Madras Agricultural Journal*, 96(1/6): 17-31.

Chopra, R.N., Badhwar, R., and Ghosh, S., 1994. *Poisonous plants of India, Indian council of agricultural research, New Delhi, India*.

De, A., Bose, R., Kumar, A., and Mozumdar, S., 2014. Management of insect pests using nanotechnology: As modern approaches. In: Targeted delivery of pesticides using biodegradable polymeric nanoparticles. Springer, New Delhi. 13: 29-33. https://doi.org/10.1007/978-81-322-1689-6_8

Dimkpa, C.O., McLean, J.E., Britt, D.W., and Anderson, A.J., 2013. Antifungal activity of ZnO nanoparticles and their interactive effect with a biocontrol bacterium on growth antagonism of the plant pathogen *Fusarium Graminearum*. *Biometals,* 26(6): 913-924. https://doi.org/10.1007/s10534-013-9667-6

Dobrucka, R., and Długaszewska, J., 2016. Biosynthesis and antibacterial activity of ZnO nanoparticles using Trifolium pratense flower extract. *Saudi Journal of Biological Sciences*, 23(4): 517-523. https://doi.org/10.1016/j.sjbs.2015.05.016

Dutta, P., Reddy, S.G.E., and Borthakur, B.K., 2013. Effect of neem kernel aqueous extract (NKAE) in tea mosquito bug *Helopeltis theivora* (Waterhouse, 1886) (Heteroptera: Miridae). *Munis Entomology and Zoology Journal,* 8(1): 213-218.

Ehrlich, H., Janussen, D., Simon, P., Bazhenov, V.V., Shapkin, N.P., Erler, C., and Worch, H., 2008. Nanostructural organization of naturally occurring composites-Part II: Silica-chitin-based biocomposites. *Journal of Nanomaterials*. 2008. https://doi.org/10.1155/2008/670235

Elek, N., Hoffman, R., Raviv, U., Resh, R., Ishaaya, I., and Magdassi, S., 2010. Novaluron nanoparticles: Formation and potential use in controlling agricultural insect pests. *Colloids and Surfaces A: Physicochemical and Engineering Aspects,* 372(1-3): 66-72. https://doi.org/10.1016/j.colsurfa.2010.09.034

El-Jaick, K.B., Fonseca, R.F., Moreira, M.A., Ribeiro, M.G., Bolognese, A.M., Dias, S.O., and Orioli, I.M., 2007. Single median maxillary central incisor: new data and mutation review. *Birth Defects Research Part A: Clinical and Molecular Teratology*, 79(8): 573-580. https://doi.org/10.1002/bdra.20380

Friedrich, T., 2015. A new paradigm for feeding the world in 2050 the sustainable intensification of crop production. *Resource Magazine*, 22(2): 18-18.

Gandhi, V.P., and Namboodiri, N.V., 2009. Economics of BT Cotton vis-a-vis Non-Bt cotton in India: A study across four major cotton growing states. *Centre for Management in Agriculture, Indian Institute of Management, Ahmedabad*. pp. 1-127.

Gao, Y., Huang, Q., Su, Q., and Liu, R., 2014. Green synthesis of silver nanoparticles at room temperature using kiwifruit juice. *Spectroscopy Letters*, 47(10): 790-795. https://doi.org/10.1080/00387010.2013.848898

Ge, F., and Ding, Y., 1996. The population energy dynamics of predacious natural enemies and their pest control activity in different cottion agroecosystems. *Kun chong xue bao. Acta entomologica Sinica*. 39(3): 266-273.

Gnanajobitha, G., Paulkumar, K., Vanaja, M., Rajeshkumar, S., Malarkodi, C., Annadurai, G., and Kannan, C., 2013. Fruit-mediated synthesis of silver nanoparticles using *Vitis vinifera* and evaluation of their antimicrobial efficacy. *Journal of Nanostructure in Chemistry*, 3(1): 67. https://doi.org/10.1186/2193-8865-3-67

Gunalan, S., Sivaraj, R., and Rajendran, V., 2012. Green synthesized ZnO nanoparticles against bacterial and fungal pathogens. *Progress in Natural Science: Materials International*, 22(6): 693-700. https://doi.org/10.1016/j.pnsc.2012.11.015

Hameed, A.S.H., Karthikeyan, C., Ahamed, A.P., Thajuddin, N., Alharbi, N.S., Alharbi, S.A., and Ravi, G., 2016. In vitro antibacterial activity of ZnO and Nd doped ZnO nanoparticles against ESBL producing *Escherichia coli* and *Klebsiella pneumoniae*. *Scientific Reports*, 6(1): 1-11. https://doi.org/10.1038/srep24312

Hoffmann, M.R., Martin, S.T., Choi, W., and Bahnemann, D.W., 1995. Environmental applications of semiconductor photocatalysis. *Chemical Reviews*, 95(1): 69-96. https://doi.org/10.1021/cr00033a004

Iravani, S., 2011. Green synthesis of metal nanoparticles using plants. *Green Chemistry*, 13(10): 2638-2650. https://doi.org/10.1039/c1gc15386b

Jain, N., Bhargava, A., and Panwar, J., 2014. Enhanced photocatalytic degradation of methylene blue using biologically synthesized "protein-capped" ZnO nanoparticles. *Chemical Engineering Journal*, 243: 549-555. https://doi.org/10.1016/j.cej.2013.11.085

Jamdagni, P., Khatri, P., and Rana, J.S., 2018. Green synthesis of zinc oxide nanoparticles using flower extract of *Nyctanthes arbortristis* and their antifungal activity. *Journal of King Saud University Science*, 30(2): 168-175. https://doi.org/10.1016/j.jksus.2016.10.002

Jayaseelan, C., Rahuman, A.A., Kirthi, A.V., Marimuthu, S., Santhoshkumar, T., Bagavan, A., and Rao, K.B., 2012. Novel microbial route to synthesize ZnO nanoparticles using *Aeromonas hydrophila* and their activity against pathogenic bacteria and fungi. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 90: 78-84. https://doi.org/10.1016/j.saa.2012.01.006

Jordan, W., 2010. Nanotechnology and pesticides. *Pesticide Program Dialogue Committee*, April, 29, 2010.

Kalishwaralal, K., Deepak, V., Ramkumarpandian, S., Nellaiah, H., and Sangiliyandi, G., 2008. Extracellular biosynthesis of silver nanoparticles by the culture supernatant of *Bacillus licheniformis*. *Materials Letters*, 62(29): 4411-4413. https://doi.org/10.1016/j.matlet.2008.06.051

Kamaraj, C., Rahuman, A.A., and Bagavan, A., 2008. Screening for antifeedant and larvicidal activity of plant extracts against *Helicoverpa armigera* (Hubner), *Sylepta derogata* (F.) and *Anopheles stephensi* (Liston). *Parasitology Research*, 03(6): 1361. https://doi.org/10.1007/s00436-008-1142-x

Kharissova, O.V., Kharisov, B.I., García, T.H., and Méndez, U.O., 2009. A review on less-common nanostructures. *Synthesis and Reactivity in Inorganic, Metal-Organic, and Nano-Metal Chemistry*, 39(10): 662-684. https://doi.org/10.1080/15533170903433196

Khot, L.R., Sankaran, S., Maja, J.M., Ehsani, R., and Schuster, E.W., 2012. Applications of nanomaterials in agricultural production and crop protection: a review. *Crop Protection*, 35: 64-70. https://doi.org/10.1016/j.cropro.2012.01.007

Kim, B.Y., Rutka, J.T., and Chan, W.C., 2010. Nanomedicine, *New England Journal of Medicine*, 363(25): 34-2443. https://doi.org/10.1056/NEJMra0912273

Klaus, T., Joerger, R., Olsson, E., and Granqvist, C.G., 1999. Silver-based crystalline nanoparticles, microbially fabricated. *Proceedings of the National Academy of Sciences,* 96(24): 13611-13614. https://doi.org/10.1073/pnas.96.24.13611

Konishi, Y., Ohno, K., Saitoh, N., Nomura, T., Nagamine, S., Hishida, H., and Uruga, T., 2007. Bioreductive deposition of platinum nanoparticles on the bacterium Shewanella algae. *Journal of Biotechnology,* 128(3): 648-653. https://doi.org/10.1016/j.jbiotec.2006.11.014

Krishnaraj, C., Jagan, E.G., Rajasekar, S., Selvakumar, P., Kalaichelvan, P.T., and Mohan, N.J.C.S.B.B., 2010. Synthesis of silver nanoparticles using *Acalypha indica* leaf extracts and its antibacterial activity against water borne pathogens. *Colloids and Surfaces B: Biointerfacez,* 76(1): 50-56. https://doi.org/10.1016/j.colsurfb.2009.10.008

Kulkarni, N., and Muddapur, U., 2014. Biosynthesis of metal nanoparticles: A review. *Journal of Nanotechnology,* 4: 1-8. https://doi.org/10.1155/2014/510246

Kyriacou, S.V., Brownlow, W.J., and Xu, X.H.N., 2004. Using nanoparticle optics assay for direct observation of the function of antimicrobial agents in single live bacterial cells. *Biochemistry,* 43(1): 140-147. https://doi.org/10.1021/bi0351110

Lall, D., Summerwar, S., and Pandey, J., 2014. *Bioefficacy of plant extracts against larvae of American bollworm Helicoverpa armigera (Nouctuidae: Lepidoptera) special reference to the effect on peritrophic membrane)*. In: International conference on chemical, civil and environmental engineering (CCEE'2014) Nov. pp. 18-19.

Lehr, P., 2014. *Global markets for biopesticides. Report Code CHM029E BCC Research*. Patent mall SDN BHD, Kuala Lumpur, Malaysia.

Lengke, M.F., Fleet, M.E., and Southam, G., 2007. Biosynthesis of silver nanoparticles by *filamentous cyanobacteria* from a silver (I) nitrate complex. *Langmuir*, 23(5): 2694-2699. https://doi.org/10.1021/la0613124

Malarvannan, S., Kumar, S.S., Prabavathy, V.R., and Sudha, N., 2008. Individual and synergistic effects of leaf powder of few medicinal plants against American bollworm, *Helicoverpa armigera* (Hubner) (Noctuidae: Lepidoptera). *Asian Journal of Experimental Biological Science,* 22(1): 79-88.

Malik, M.F., Khan, A.G., Hussainy, S.W., and Amin, M., 2002. Scouting and control of *Helicoverpa armigera* by synthetic pheromone technology in apple. *Asian Journal of Plant Sciences,* 3: 663-664.

Martínková, L., Uhnáková, B., Pátek, M., Nešvera, J., and Křen, V., 2009. Biodegradation potential of the genus Rhodococcus. *Environment International*, 35(1): 162-177. https://doi.org/10.1016/j.envint.2008.07.018

Mokhtari, N., Daneshpajouh, S., Seyedbagheri, S., Atashdehghan, R., Abdi, K., Sarkar, S., and Shahverdi, A.R., 2009. Biological synthesis of very small silver nanoparticles by culture supernatant of *Klebsiella pneumonia*: The effects of visible-light irradiation and the liquid mixing process. *Materials Research Bulletin*, 44(6): 1415-1421. https://doi.org/10.1016/j.materresbull.2008.11.021

Movahedi, F., Masrouri, H., and Kassaee, M.Z., 2014. Immobilized silver on surface-modified ZnO nanoparticles: As an efficient catalyst for synthesis of propargylamines in water. *Journal of Molecular Catalysis A: Chemical,* 395: 52-57. https://doi.org/10.1016/j.molcata.2014.08.007

Murugan, K., Sivaramakrishnan, S., Senthil Kumar, N., Jeyabalan, D., and Senthil Nathan, S., 1998. Synergistic interaction of botanicals and biocides nuclear polyhedrosis virus on pest control. *Journal of Scientific and Industrial Research*, 57(10-11): 732-739.

Nachiyar, V., Sunkar, S., and Prakash, P., 2015. Biological synthesis of gold nanoparticles using endophytic fungi. *Der Pharma Chem*. 7(11): 31-38.

Nagajyothi, P.C., An, T.M., Sreekanth, T.V.M., Lee, J.I., Lee, D.J., and Lee, K.D., 2013. Green route biosynthesis: Characterization and catalytic activity of ZnO nanoparticles. *Materials Letters,* 108: 160-163. https://doi.org/10.1016/j.matlet.2013.06.095

Nowack, B., and Bucheli, T.D., 2007. Occurrence, behavior and effects of nanoparticles in the environment. *Environmental Pollution*, 150(1): 5-22. https://doi.org/10.1016/j.envpol.2007.06.006

Otari, S.V., Patil, R.M., Nadaf, N.H., Ghosh, S.J., and Pawar, S.H., 2012. Green biosynthesis of silver nanoparticles from an actinobacteria *Rhodococcus* sp. *Materials Letters,* 72: 92-94. https://doi.org/10.1016/j.matlet.2011.12.109

Owolade, O.F., Ogunleti, D.O., and Adenekan, M.O., 2008. Titanium dioxide affects disease development and yield of edible cowpea. Agriculture *Food Chem*istry, 7(50): 2942-2947.

Pati, R., Mehta, R. K., Mohanty, S., Padhi, A., Sengupta, M., Vaseeharan, B., and Sonawane, A., 2014. Topical application of zinc oxide nanoparticles reduces bacterial skin infection in mice and exhibits antibacterial activity by inducing oxidative stress response and cell membrane disintegration in macrophages. *Nanomedicine: Nanotechnology, Biology and Medicine*, 10(6): 1195-1208. https://doi.org/10.1016/j.nano.2014.02.012

Patil, B.N., and Taranath, T.C., 2016. *Limonia acidissima* L. leaf mediated synthesis of zinc oxide nanoparticles: A potent tool against *Mycobacterium tuberculosis*. *International Journal of Mycobacteriology,* 5(2): 197-204. https://doi.org/10.1016/j.ijmyco.2016.03.004

Pavani, K.V., Kumar, N.S., and Sangameswaran, B.B., 2012. Synthesis of lead nanoparticles by *Aspergillus* species. *Polish Journal of Microbiology*, 61(1): 61-63. https://doi.org/10.33073/pjm-2012-008

Prasad, K., and Jha, A.K., 2009. ZnO nanoparticles: synthesis and adsorption study, *Nature Science,* 1: 129–135. https://doi.org/10.4236/ns.2009.12016

Prasad, R., Kumar, V., and Prasad, K.S., 2014. Nanotechnology in sustainable agriculture: Present concerns and future aspects. *African Journal of Biotechnology*, 13(6): 705-713. https://doi.org/10.5897/AJBX2013.13554

Pulit-Prociak, J., Chwastowski, J., Kucharski, A., and Banach, M., 2016. Functionalization of textiles with silver and zinc oxide nanoparticles. *Applied Surface Science*, 385: 543-553. https://doi.org/10.1016/j.apsusc.2016.05.167

Ragaei, M., and Sabry, A.K.H., 2014. Nanotechnology for insect pest control. *International Journal of Science, Environment and Technology*, 3(2): 528-545.

Rahman, A.K.M.Z., Haque, M.H., Alam, S.N., Mahmudunnabi, M., and Dutta, N.K., 2014. Efficacy of botanicals against *Helicoverpa armigera* (Hubner) in tomato. *The Agriculturists,* 12(1): 131-139. https://doi.org/10.3329/agric.v12i1.19868

Rajeshkumar, S., 2016. Anticancer activity of eco-friendly gold nanoparticles against lung and liver cancer cells. *Journal of Genetic Engineering and Biotechnology,* 14(1): 195-202. https://doi.org/10.1016/j.jgeb.2016.05.007

Raliya, R., and Tarafdar, J.C., 2013. ZnO nanoparticle biosynthesis and its effect on phosphorous-mobilizing enzyme secretion and gum contents in Clusterbean (*Cyamopsis tetragonoloba* L.). *Agricultural Research,* 2(1): 48-57. https://doi.org/10.1007/s40003-012-0049-z

Ramesh, M., Anbuvannan, M., and Viruthagiri, G.J.S.A.P.A.M., 2015. Green synthesis of ZnO nanoparticles using *Solanum nigrum* leaf extract and their antibacterial activity. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 136: 864-870. https://doi.org/10.1016/j.saa.2014.09.105

Ramya, M., and Subapriya, M.S., 2012. Green synthesis of silver nanoparticles. *International Journal of Pharma Medicine Biological Sci*ences, 1(1): 54-61.

Ramya, S., Rajasekaran, C., Sundararajan, G., Alaguchamy, N., and Jayakumararaj, R., 2008. Antifeedant Activity of leaf aqueous extracts of selected medicinal plants on VI instar larva of *Helicoverpa armigera*. *Ethnobotanical Leaflets,* 12: 938-943.

Resham, S., Khalid, M., and Kazi, A.G., 2015. *Nanobiotechnology in agricultural development*. In: Plant Omics: The Omics of Plant Science, Springer, New Delhi. pp. 683-698. https://doi.org/10.1007/978-81-322-2172-2_24

Sadowski, Z., 2010. Biosynthesis and application of silver and gold nanoparticles. *Silver nanoparticles*. pp. 257-276. https://doi.org/10.5772/8508

Sahayaraj, K., and Rajesh, S., 2011. Bionanoparticles: synthesis and antimicrobial applications. *Science against Microbial Pathogens: Communicating Current Research and Technological Advances*, 23: 228-244.

Sahoo, S.C., 2014. Use of nanotechnology in agriculture. Scientia Horticulture. pp.19.

Sangani, M.H., Moghaddam, M.N., and Mahdi, M., 2015. Inhibitory effect of zinc oxide nanoparticles on *pseudomonas aeruginosa* biofilm formation, *Nanomedicine Journal,* 2: 121–128.

Scrinis, G., and Lyons, K., 2007. The emerging nano-corporate paradigm: Nanotechnology and the transformation of nature, food and agri-food systems. *International Journal of Sociology of Agriculture and Food*, 15(2): 22-44.

Shahverdi, A.R., Minaeian, S., Shahverdi, H.R., Jamalifar, H., and Nohi, A.A., 2007. Rapid synthesis of silver nanoparticles using culture supernatants of Enterobacteria: A novel biological approach. *Process Biochemistry*, 42(5): 919-923. https://doi.org/10.1016/j.procbio.2007.02.005

Shamsuzzaman, A., Mashrai, H., Khanam, R.N., and Aljawfi, R.N., 2013. Biological synthesis of ZnO nanoparticles using *C. albicans* and studying their catalytic performance in the synthesis of steroidal pyrazolines, *Arabian. Journal of Chemistry,* 10: 1530-1536. https://doi.org/10.1016/j.arabjc.2013.05.004

Shankar, S. S., Rai, A., Ankamwar, B., Singh, A., Ahmad, A., and Sastry, M., 2004. Biological synthesis of triangular gold nanoprisms. *Nature Materials*, 3(7): 482-488. https://doi.org/10.1038/nmat1152

Singh, S., 2012. *IIT Madras develops nanoparticles to fight pesticide residues*.

Slowik, T.J., Green, B.L., and Thorvilson, H.G., 1997. Detection of magnetism in the red imported fire ant (*Solenopsis invicta*) using magnetic resonance imaging. *Bioelectromagnetics: Journal of the Bioelectromagnetics Society, The Society for Physical Regulation in Biology and Medicine, The European Bioelectromagnetics Association*, 18(5): 396-399. https://doi.org/10.1002/(SICI)1521-186X(1997)18:5<396::AID-BEM7>3.0.CO;2-Y

Subashini, H.D., Malarvannan, S., and Pillai, R.R., 2004. *Dodonaea angustifolia*–a potential biopesticide against *Helicoverpa armigera*. *Current Science,* 86(1): 26-28.

Sullivan, M., and Molet, T., 2007. *CPHST Pest Datasheet for Helicoverpa armigera*. USDA-APHIS-PPQ-CPHST.

Sundararajan, G., and Kumuthakalavalli, R., 2001. Antifeedant activity of aqueous extract of *Gnidia glauca* Gilg. and *Toddalia asiatica* Lam. on the gram pod borer, *Helicoverpa armigera* (Hbn). *Journal of Environmental Biology*, 22(1): 11-14.

Sundrarajan, M., Ambika, S., and Bharathi, K., 2015. Plant-extract mediated synthesis of ZnO nanoparticles using *Pongamia pinnata* and their activity against pathogenic bacteria. *Advanced Powder Technology*, 26(5): 1294-1299. https://doi.org/10.1016/j.apt.2015.07.001

Tamil Nadu agriculture University Coimbatore, extension initiative of TNAU. TNAU agritech portal, India.

Vanathi, P., Rajiv, P., Narendhran, S., Rajeshwari, S., Rahman, P.K., and Venckatesh, R., 2014. Biosynthesis and characterization of phyto mediated zinc oxide nanoparticles: A green chemistry approach. *Materials Letters*, 134: 13-15. https://doi.org/10.1016/j.matlet.2014.07.029

Velayutham, K., Rahuman, A.A., Rajakumar, G., Roopan, S. M., Elango, G., Kamaraj, C., and Siva, C., 2013. Larvicidal activity of green synthesized silver nanoparticles using bark aqueous extract of *Ficus racemosa* against *Culex quinquefasciatus* and *Culex gelidus. Asian Pacific Journal of Tropical Medicine*, 6(2): 95-101. https://doi.org/10.1016/S1995-7645(13)60002-4

Vigneshwaran, N., Ashtaputre, N.M., Varadarajan, P.V., Nachane, R.P., Paralikar, K.M., and Balasubramanya, R.H., 2007. Biological synthesis of silver nanoparticles using the fungus *Aspergillus flavus*. *Materials Letters,* 61(6): 1413-1418. https://doi.org/10.1016/j.matlet.2006.07.042

Wajnberg, E., Acosta-Avalos, D., El-Jaick, L.J., Abraçado, L., Coelho, J.L.A., Bakuzis, A.F., and Esquivel, D.M.S., 2000. Electron paramagnetic resonance study of the migratory ant *Pachycondyla marginata* abdomens. *Biophysical Journal,* 78(2): 1018-1023. https://doi.org/10.1016/S0006-3495(00)76660-4

Watson, G.S., and Watson, J.A., 2004. Natural nano-structures on insects possible functions of ordered arrays characterized by atomic force microscopy. *Applied Surface Science,* 235(1-2): 139-144. https://doi.org/10.1016/j.apsusc.2004.05.129

Wieczorek, A., 2003. *Use of biotechnology in agriculture-benefits and risks*. Biotechnology.

Wilkins, R.M., 2004. *Controlled release technology, agricultural*. In: Seidel A. (ed.) Kirk-Othmer encyclopedia of chemical technology. 5th Ed. New Jersey: John Wiley and Sons. https://doi.org/10.1002/0471238961.0107180907150518.a01.pub2

Willner, I., Baron, R., and Willner, B., 2006. Growing metal nanoparticles by enzymes. *Advanced Materials,* 18(9): 1109-1120. https://doi.org/10.1002/adma.200501865

Xiao, L., Liu, C., Chen, X., and Yang, Z., 2016. Zinc oxide nanoparticles induce renal toxicity through reactive oxygen species. *Food and Chemical Toxicology*, 90: 76-83. https://doi.

org/10.1016/j.fct.2016.02.002

Yang, F.L., Li, X.G., Zhu, F., and Lei, C.L., 2009. Structural characterization of nanoparticles loaded with garlic essential oil and their insecticidal activity against *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae). *Journal of Agricultural and Food Chemistry*, 57(21): 10156-10162. https://doi.org/10.1021/jf9023118

Zhang, G., Zhang, J., Xie, G., Liu, Z., and Shao, H., 2006. Cicada wings: a stamp from nature for nanoimprint lithography. *Small*, 2(12): 1440-1443. https://doi.org/10.1002/smll.200600255

Zong, Y., Li, Z., Wang, X., Ma, J., and Men, Y., 2014. Synthesis and high photocatalytic activity of Eu-doped ZnO nanoparticles. *Ceramics International*, 40(7): 10375-10382. https://doi.org/10.1016/j.ceramint.2014.02.123