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Rohit Ramesh
M. Sc. Student, Department of Agricultural Entomology, BACA, AAU, Anand, Gujarat, India

Dabhi MR
Assistant Professor (Ento.) Department of Agricultural Entomology, COA, AAU, Jabugam, Gujarat, India

Vinod B Mor
Assistant Professor (Agronomy), COA, AAU, Jabugam, Gujarat, India

Correspondence
Rohit Ramesh
M. Sc. Student, Department of Agricultural Entomology, BACA, AAU, Anand, Gujarat, India

Nanopesticides as emerging agri-chemical formulations for income maximization

Rohit Ramesh, Dabhi MR and Vinod B Mor

Abstract
Pesticides denotes a wide range of agro-chemicals, those are extensively used in agriculture for protection of crops from diseases, pests and weeds. Pesticides are exploited both extensively and intensively to minimize these losses and around 3 billion tons of pesticides are employed for the same. The biggest hurdle that lead to the failure of these pesticides was the water-insolubility of these formulations. A new advent in this scenario is the nanopesticides which relies on the nano-sizing or the reduction of droplet size to a billionth, to enhance the surface area, activity and water solubility of the chemicals. Nanocapsules have shown controlled release and slow degradation of active ingredient (AI), making them more efficient in controlling plant disease and pests. They have the potential to revolutionize the agrochemical sector due to its superior physical and chemical properties, by virtue of which, it has better application in pest management strategies. These molecules might probably become the answer to the deleterious effects caused by the over-exploitation of pesticides. They can bring down the quantity of pesticides currently being used around the world for pest management methods, and thus restore the balance of ecosystem, at the same time, ensure food safety and food security.
The combination of low efficiency and the environmental backlash of conventional pesticides like the environmental degradation, non-biodegradability, bio magnification, etc. makes the nanopesticides a safer alternative to the conventional formulations. Moreover, due to its higher efficiency, it is more cost-effective and thus reduces the expenditure on plant protection measures. Botanical insecticides associated with nanotechnology that are based on active agents isolated from plant extracts as well as essential oils are derived from certain plants. At a time when the conventional pesticides pose an immense threat to the quality of environment and the health of the organisms, more emphasize should be given on development of nano-formulation of pesticides, which proves to be more potent and selective over the conventional formulations. Though these formulations have not reported to cause any acute toxicity in the non-target organisms till date, more thrust should be given on this aspect to come up with ways to nullify the short comings before its ingression in agriculture.

Keywords: nanopesticides, income maximization

Introduction
The term pesticide denotes a wide range of agro-chemicals, those are extensively used in agriculture for protection of crops from diseases, pests and weeds. These include insecticides, herbicides, fungicides, molluscicides, nematicides, rodenticides, etc. Agricultural production constantly encounters high magnitude of losses due to various agents like insect pests, pathogens and weeds. It is estimated that the losses incurred world-wide by the insects, pathogens and weeds are about 40%. In monetary terms, it adds up to around 2000 billion dollar economic loss per year. Pesticides are exploited both extensively and intensively to minimize these losses and around 3 billion tons of pesticides are employed for the same (Peshin and Dhawan, 2009) [13]. Such indiscriminate use and misuse of pesticides have caused severe degradation of environment and associated organisms. The initial benefits derived from the usage of pesticides like higher pest control and productivity are now down-sized due to the inability of these to control the pests which they could control earlier. The reasons being development of resistance, ineffectiveness of formulations, and the impact on non-target organisms. Though alternatives were employed instead of synthetic pesticides, they failed to produce the same results.
The biggest hurdles that lead to the failure of these pesticides were the water-insolubility of these formulations. Traditionally, these insoluble chemicals were applied as dusts, dissolved in organic solvents and or in organic based emulsions (EC). These methods proved to be inefficient, costly, involved indiscriminate dumping of pesticides in the environment.

The major advantages that may be acquired by the downsizing of the particles are:

- The improvement of efficiency due to higher surface area and higher solubility
- The induction of systemic activity due to smaller particle size and higher mobility, and
- The lower phyto-toxicity due to elimination of organic solvent.

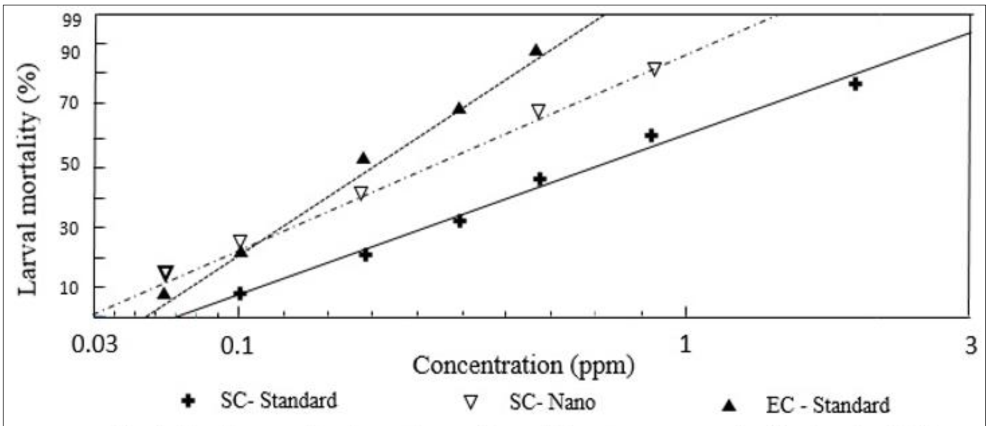
A new advent in this scenario is the nanopesticides which relies on the nano-sizing or the reduction of droplet size to a billionth, to enhance the surface area, activity and water solubility of the chemicals.

History of nanoparticles in agro-industry

Nano-sizing was first undertaken in the medical field during the 1970s. The first report on synthetic nanoparticles was made by Speiser and co-workers from ETH in Zurich during this period (Kopf *et al.*, 1976) [10]. In the case of crop-protection chemicals, the first breakthrough made its way by employing nano-sized macromolecules are carrier particles. And thus, polycaprolactone and polylactic acid nanospheres (NS) were tested for the nano-encapsulation of the insecticide ethiprole (Boehm *et al*., 2003) [2]. The attempt was a success as the nanospheres made it possible to enhance the penetration through the leaves and consequently boost the systemic activity compared to the conventional formulations, although it was delimited because of the inability of the nanospheres to provide a controlled release of active ingredient. Further down the road, controlled release was observed by Liu *et al*. (2001) [11], who managed to incorporate the fungicides tebuconazole and chlorothalonil into nanoparticles (100-250 nm) of polyvinyl pyridine and polyvinyl pyridine co-styrene.

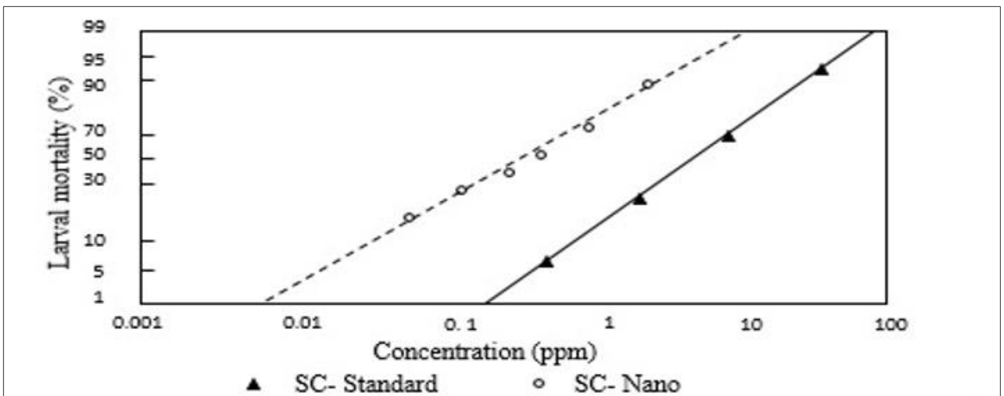
Modern day approaches to nanopesticides

In recent years, the Chinese scientists obtained patents for incorporation of insecticides like ivermectin (Shang *et al*., 2004) [15, 17] and for acetamiprid (Zheng and Shang, 2004) [15, 17] in to polymeric nanocapsules. Furthermore, researches were found successful in the use of nano-sized inorganic particles like SiO_2, TiO_2, Fe_2O_3, or Al_2O_3 as carriers of various pesticides (Wang *et al*., 2004) [17]. Rimon (Novaluron) is a synthetic insecticide which belongs to benzoylurea group and functionally an insect growth regulator, which provides effective control in case of lepidopteran larvae, whiteflies, leaf miners, as well as all development stages of mosquito. A series of assays were conducted on novaluron to test the toxicity of nano-sized novaluron as soluble concentrate against a standard EC formulation and a conventional SC formulation. The experiments were carried out on cotton whitefly, *Bemisia tabaci*, and the Egyptian cotton leaf worm, *Spodoptera littoralis*. The results showed that the soluble concentrate of the nanopesticide was on par with the EC formulation and 2.5 times more potent than the simple SC formulation (Bryne *et al*., 1990; Horowitz and Ishaaya, 1994; Horowitz *et al*., 1996) [3, 7, 8].



Toxicity of nano-sized novaluron formulation as compared with standard EC and SC formulations expressed in mortality curves

Fig 1



Toxicity of the nano-sized novaluron SC formulation as compared with the standard commercial SC formulation expressed in mortality curves on probit scales

Fig 2

The effect of 0.3 mg AI/l nano-sized novaluron formulation as compared to the standard EC and SC formulations on *Bemisia tabaci* first-instar nymphs

Formulation	No. of nymphs	Pupation % ± SEM
Untreated	113	98 ± 2a
SC-10 (commercial)	72	79 ± b
SC-10 (nano-sized)	93	28 ± 5c
EC-10 (commercial)	156	28 ± 8c

Data are averages ± SEM of five replicates of 11-48 nymphs each. Means followed by the same letter do not significantly differ at P = 0.05.
SC-10 (Commercial): MVPS: 1500 nm; D90VPS: 3500 nm
SC-10 (nano-sized): MVPS: 350 nm; D90VPS: 520 nm

Nanocapsules have shown controlled release and slow degradation of active ingredient (AI), making them more efficient in controlling plant disease and pests. A variety of polysaccharide materials have been tested and used in the synthesis *i.e.* chitosan, Polyethylene Glycol (PEG), starch, cellulose and polyester materials (Chippa, 2017) [5]. Bhan *et al*. (2014) [1] made use of melt-dispersion technology to develop a nanopesticide wherein insecticides like imidacloprid and temephos were encapsulated with PEG, which proved highly effective against *Culex quinquefasciatus*. Furthermore, fungicides like carbendazim and tebuconazole were encapsulated in solid lipid and polymeric nano-capsules (Campos *et al*., 2015) [4]. To reduce the harmful effects of herbicides, Poly epsilon caprolactone (PCL) nano-capsule was developed for the controlled release of Atrazine and found an enhanced activity of atrazine compared to standard formulation (Oliviera *et al*., 2015) [12].

Future prospects in nanopesticides

Nanopesticides have the edge over the conventional molecules according to the various experimental results. They have the potential to revolutionize the agrochemical sector due to its superior physical and chemical properties, by virtue of which, it has better application in pest management strategies. These molecules might probably become the answer to the deleterious effects caused by the over-exploitation of pesticides. They can bring down the quantity of pesticides currently being used around the world for pest management methods, and thus restore the balance of ecosystem, at the same time, ensure food safety and food security. The ability to release the active ingredient slowly and efficiently over a longer period would be able to tackle the problems of eutrophication and pesticide residue accumulation. Still, a great deal of research should be carried out to sharpen the technique, if it is to successfully replace the existing molecules. According to the review of Fraceto *et al.*, some areas which require emphasis are:

- Integration of the principles of environmental sustainability and green chemistry into the development of nanopesticides to maximize its efficiency.
- Scaling up the production level of nano-suspensions to the commercial standards.
- Intensive research to be carried out on the determination of acute and chronic toxicity of nanopesticides on the environment.
- Regulation standards to be improved in the handling of nanopesticides.
- Determination of fate of nanopesticides in the environment should be assessed.
- Comparison of the activity of the nano-formulations to the present molecules to the field level to make out the practical applicability.

Role of nanopesticides in maximizing income of producer

The combination of low efficiency and the environmental backlash of conventional pesticides like the environmental degradation, non-biodegradability, biomagnification, etc. makes the nanopesticides a safer alternative to the conventional formulations. Moreover, due to its higher efficiency, it is more cost-effective and thus reduces the expenditure on plant protection measures. Integrating the nanopesticides formulations with the modern day crop protection practices can maximize the returns of the producer. The nano-based formulations address the above issues in the following ways:

- **Energy:** Nanopesticides are applied at smaller volumes and less frequently than conventional pesticides, resulting in less fuel expenditure for spraying operation.
- **Water:** Nanopesticides are more effective and require only very less volumes for application compared to the conventional pesticides. Less frequent and precise application of these molecules reduces wastage of non-point water.
- **Pesticide efficiency and Crop productivity:** Nanotechnology promises higher yields and lower input costs by streamlining the agricultural management and thereby reducing wastage of resources and costs (Sheykhbaglou *et al*, 2010).

Considerable potential for increasing agricultural productivity is offered not only by nano-formulations of man-made insecticides but also by botanical insecticides associated with nanotechnology that are based on active agents isolated from plant extracts as well as essential oils derived from certain plants (De Oliviera *et al.*, 2014) [4].

Conclusion

Both nanotechnology and nanoparticle engineering were instrumental in providing breakthroughs in the field of pharmaceuticals and medicine since the 1970s (Rosen and Abribat, 2005) [14], but it haven’t had such an impact on agriculture and the agro-chemical industry. But it is believed that a comparable transformation and paradigm shift will occur in the agricultural sector with the advent of nano-techonogy in agriculture. At a time when the conventional pesticides pose an immense threat to the quality of environment and the health of the organisms, more emphasize should be given on development of nano-formulation of pesticides, which proves to be more potent and selective over the conventional formulations. Moreover, the nano-formulations are more efficient and their bioavailability and persistence is higher. Since, they do not involve the use of organic solvents, they are economically sound and environmentally safe. Though these formulations have not reported to cause any acute toxicity in the non-target organisms till date, more thrust should be given on this aspect to come up with ways to nullify the short comings before its ingression in agriculture.

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