E-ISSN: 2788-9270
P-ISSN: 2788-9262
www.pharmajournal.net
NJPS 2022; 2(1): 17-23
Received: 27-10-2021
Accepted: 09-12-2021

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Bioactivity of insecticides nanoparticles for pest control: Review

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DOI: https://doi.org/10.22271/27889262.2022.v2.i1a.31

Abstract
Although nano-particles (NPs) ability be exploited as insecti-cides by themselves, they ability to be movers for insecti-cidal chemicals. Current works recommends in order to the lesser the NP magnitude, the larger the noxiousness and dissemination into the insect's soma. However, here is an absence of works relating to the method of achievement inside insects. This presentation treatise précises the presently obtainable entomological educations at the apparatuses of NP–insect relations. Outwardly, NPs impact coloration and safety of the integument, though on the inside they encourage invulnerable replies and change gene appearance directing to different protein, lipid, and carbohydrate breakdown lengthways through cellular poisonousness that damages development and propagation of the insect. Accordingly, insects are debilitated owing to the disturbance of the nutritious consumption, manufacture of retroactive oxygen species and evolution changed bio-chemical effectiveness though around NPs ability encourage development and besides reduce the impacts of non-goal poisonousness.

Keywords: Nano-pesticides, insects, toxicity, protective, mechanism, AgNPs

1. Introduction
Insecticides yet continue a actual significant constituent over the methods for vigorous controller of the pest. Meanwhile united pest organization (IPM) gained support as a preferred process of pest manager, numerous efforts have been created to protect usual or proclaimed adversaries by choosing discerning insecticides [1, 2]. As per the Global Society for Calibration, ISO, ingredients by exterior sizes or interior constructions on a nano measure are mentioned to as nanomaterials and the phrase nano measure is usually restricted to around 100 nmj in order to their nano measure, nano ingredients display possessions and performance that vary after, or are extra to, these of rougher wholesale ingredients with alike biochemical conformations. Debate occurs whether to comprise ingredients for instance transporters as nano ingredients which normally have external distances a lot greater than 100-nm while the interior active structures may be lesser than 100-nm. Nano pesticides, thus might or might not drop inside the description of nano ingredients. complemented that 'Nano pesticides might be utilized to depict any pesti-cide preparation that (a) deliberately contains objects in the nano-meter magnitude variety, (b) is specified by a "nano" preface (e.g., nano mixture, nano compound), and/or (c) is demanded to have original characteristic related through the little magnitude' [3]. In this review, we will converse the numerous kinds of nano pesticide formulations, their preparedness, effectiveness and implementation with transitory explanations on their conservational destiny. Providentially, the fast growth of the nanotechnology sideways through substitute approaches intended to output remainder-release nano mixtures with augmented insecticidal effectiveness and minimum environmental perseverance, sideways with slight harmful consequence to hominoid wellbeing and the climate. Also, the prudent implementation of pesticide practice ability retards the durability growth contrary to the insecticides. In current years, diverse nanoparticles (NPs) own advanced, specifically, Ag, CuO, MgO, and ZnO, with inveterate effective insecticidal vigor also single or in the joint formula through diverse medications contrary to the insects of diverse orders [4]. Fascinatingly, to the finest of our information, a scarce investigate documents have been revealed to learning the collective impacts of NPs with biological pesticides to controller the impairment triggered to florae by these insect pests [5, 6 and 7]. Additionally, semjointeri NPs offer a possible resolution to eliminate the remainders of pesticides during photocatalytic effectiveness [8, 9, 10]. As well promote us to set down a new lime nanotechnology to regulator insect pests through a cooperative method

sideways through succeeding degeneration over the photocatalytic action and hereafter are ecologically intimate [11].

2. Insecti-cide-loaded nano-particles

In greatest suitcases nano-particles are created as a transporter of pesti-cides and their insecti-cidal effectiveness is not deem. Permeable empty silica nano-particles (PHSN) were settled through a sol–gel way via mineral calcium carbonate nano-particles. PHSN was used by way of a pesticide transporter and initial overloaded through avermectin. The writers described that liberation shape of avermectin rely on cortex width, site of lading (exterior superficial, the barrier or the internal central of the PHSN transporter) and additional issues for example pH and temperature. Though, PHSN efficiently measured liberation of avermectin [12, 13]. The lubricant-in-liquid nano suspension (O/W) was created to subedit liquid-unsolvable insecticides for example β-cypermethrin (β-CP) [14]. The preparation reduced the condensation compulsory for active regulator in marketable sprinkle implementation, shorn of mislay efficacy and improved steadiness of pesticides. Imidacloprid is too single of the insecticides compressed through chitosan and sodium alginate over coating-by coating self-assemblage [15]. Remainder of the new imidacloprid was reveal underneath the border in the soybean plant and a lot lesser than the USA Environmental Protection Agency's Extreme Remainder Level [16]. Advanced Nano silver coupled to the pyrethroid pesticide, deltamethrin who was efficient versus arthropod paths, for example mosquitoes [17]. Pyrifluquinazon nanoparticles by efficient measured-liberation advantage was advanced by [18] and its efficiency was originating contrary to *Myzus persicae.* Fabrics were original and laden by pyrethroid nano capsules to raise the toughness of insecticide uniform afterward consecutive wash and astral contact [19]. Lately, usual founded insecticides are measured as biopesticides. Created polyethylene glycol covered nanoparticles by melt-spreading technique and encumbered by garlic energetic lubricant [20]. They specified that oil-laden nanoparticles were additional efficient than the vital oil counter to stowed creation insect pests and the encapsulation procedure augmented the toughness of the vital oil level extra than 5 months. Advanced cumin and ajwain important lubricant-laden nano lotions and announced perseverance and insecticidal effectiveness of oil-overloaded nanogels versus around stocked produce insect pests was nearby 3-6-doubling extra than the lubricants [21].

3. Nano-particles as Carriers for Insecti-cides

Lading insecti-cides interested in nano-particles main ongoing in the initial 2000s ago then, traditional insecti-cides (27 educations) and bio vigorous composites by insecti-cidal characteristic (13 educations) have been showed by a variety of nano-particles. those educations have discovered eight diverse MoA and a variety of fundamental lubricants (not involved in Insecticide durability Achievement Commission (IRAC) classification). The greatest usually inspected nanoparticle transporters were silica (8 educations), chitosan (11 educations), and lipids (4 educations). *Spodoptera litura* (5 educations), *Tetranychus urticae* (4 educations), and *Helicoverpa armigera* (4 educations) were the greatest general goal pests. In those searches, the investigators intended to get better little liquid-solubility, reduction volatilization, recover stabilization, and afford deliberate emission of the energetic molecules. Insecti-cides that have little liquid-solvable necessitate biological diluters to assistance solvable the pesti-cide, which rises the charge and poisonousness of the insecti-cide. As an alternative, nano-elements ability be utilized to rise the solubility, thus decrease the poisonousness. Up to now, short-liquid-solvable insecticides have been effectively burdened interested in altered chitosan [22, 23, 24 and 25] and permeable silica [26]. Though, nobody of those educations experienced for concentrated conservational poisonousness. Via changed chitosan nano-elements to burden the aquaphobic insecti-cide azadirachtin, [24] displayed satisfactory suppression of cell propagation in S. litura ovarian cell outlines, and continued medication liberation. In extra education, displayed an augmentation in acceptance and advanced death when *H. armigera* larvae were exposed to *dendrimers burdened* with aquaphobic thia-methoxam. Remarkably, *H. armigera* is not generally vulnerable to thia-methoxam [27]. Nevertheless, after laden on dendrimer nano-elements, an important augmentation in poisonousness was detected. An augmentation in death was also visible once anacardic acid (a cashew nutshell fluid extractor) was inserted into LDH nano-elements [28]. Once immediately sprinkle against the covering of *S. litura* or used onto mustard greeneries, an augmentation in death was detected through the LDH preparation, associated to anacardic acid single. These educations highpoint the possibility advantage of utilize nano-elements to get better the solvable of vigorous vaporization or volatilization of the vigorous is additional mutual matter connected with the injury of insecticide next to implementation. Vital lubricants are identified for encouraging insecticidal impacts, but quickly vaporization owing to their biochemical unpredictability in the occurrence of ambiance, sunlit, humidity, and altitude temperatures, sprinkle SLN nanoelement-compressed *Artemisia arborescence* L. important lubricant interested in glazier ampoules, and detected 45.5% vaporization through a preliminary eruption emission, associated to 80% vaporization of crucial lubricant single, afterward 48 h [29]. In additional education, garlic important lubricant was compressed into poly-ethylene-glycol (PEG) and practical to gathered rice, before invaded by red flour beetles (*Tribolium castaneum*) [30]. Later 5 months, 80% death was experiential by the nano-element preparation, related to 11% death by crucial lubricant single. Likewise, [31] handled castor greeneries through pinene and linalool-condensed silica disseminated in acetone. The writers described that *S. litura* and castor semi-looper eat on processed greeneries had lesser eating effectiveness, directing to decease because of malnourishment. These studies effectively displayed that the connotation of the vigorous with nano-particles enhanced the dispersal subjects. Extra motivative to progress nano insecti-cides is to augmentation the steadiness of the vigorous particles and afford a continued emission that would permit for a reduction in insecti-cide utilized and ameliorated security. In arena experiments, create that okra-bhindi vegetation sprinkle by sodium-alginate-condensed imidacloprid were merely as efficient as imidacloprid single [32]. In additional arena education, handled Brassica-Chinese with silica-condensed chlorfenapyr to accomplish alike or additional efficient regulator counter to the diamond-back moth (*Plutella xylostella*) above a three-daytime interval [33]. Additional education creates that nourishing termites with

fipronil, laden interested in nano-elements by a silica cortex of greater cortex width and a lubricant central, supply a constant emission by no original eruption emission, therefore permitting the employee termites to possibly load the attraction backward to the colony [34]. Associated to the conventional insecti-cide, silica-burdened fipronil expanded the 100% death gap by 3 daytimes, permitting best removal of the settlement. Overloaded azadirachtin against zinc-oxide or chitosan nano-elements, and examined the effectiveness above 180 daytimes in peanut bruchid storing circumstances [35]. Neem-seed grain extractor, overloaded to zinc-oxide nano-particles, comprise peanut bruchid with 54.61% mass damage comparison to extra preparations examined. Deliberate emission of energetic particles could similarly possibly reduction the poisonousness of the insecticides. Up to now, 4 educations have examined if continued emission of insecticides as of nanoelements could reduction poisonousness. For instance, after experiment for cytopoisonousness of imidacloprid overloaded to sodium alginate nanoelements, demanded "that those exams obviously detect that at this concentricity burdened-pesticide nano preparation is actual minimal poisonous than authentic pesti-cide" [32]. Nevertheless, lone a minor variance was watched, and no arithmetical investigation was managed. Alternatively, [36] watched a reduction in poisonousness impact on zebrafish through empty poly-meric cortex nano-element compressed cyhalothrin, and the greater micron- volume elements of the similar conformation, once associated to the UN subedit insecti-cide cyhalothrin. Similarly detected a reduction in poisonousness in mouse fibro-blast cell stripes once handled by zein nanoelement compressed botanic expellers, comparison to the botanic expellers single [37]. Likewise, carvacrol and linalool, laden to chitosan nanoelements, furthermore reduced the poisonousness in 2 fibro-blast cell stripes [31]. Extra educations are obligatory to check the discounts in insecti-cide poisonousness owing to nano-element encapsulation, nonetheless these educations afford a hopeful beginning in (Figure 1).

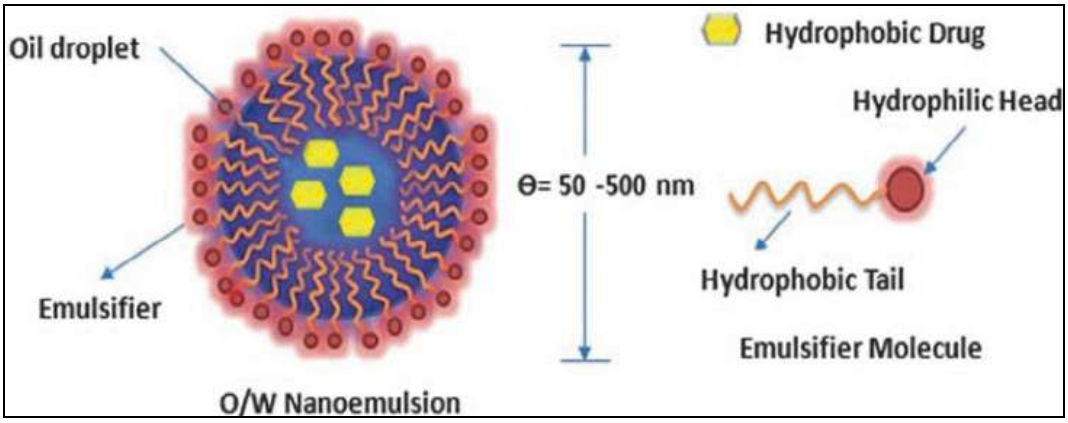

Fig 1: Suspension contents [38]

4. Accommodation of Insecticide Nano capsules

The nano-capsules are colloidal- volume, vesicular organizations in who the vigorous component is restricted to a tank or inside an echoing enclosed by a poly-mer casing or covering [39]. every nano-element requirement an appropriate conserve to avoid there since suffering accumulation throughout the response that is to be stimulated. Poly-mer–nano-element insides are appropriate ingredients utilized for the target of investing or reinforcing the single characteristic of the nano-elements, although the poly-mer medium ability controller harbor –visitor communications to guarantee the fine-distinct latitudinal circulation of nano-elements [40]. The greatest significant constituent of insecti-cide nano tablets is the poly-mer. There are numerous foundations of poly-mers for example poly-carbohydrates (e.g., chitosan, alginates, starch) and poly-esters (e.g., poly-ε-caprolactone, poly-ethylene-glycol) in order to have been utilized for the setting up of nano-insecti-cides. The primary construction comprising poly-mer for restrain liberation of bio-insecti-cides beginning in the primary 1970s. By the increasing consciousness for ecological contamination, implementation of bio-degradable and bio harmonious poly-mers of usual source is favored above the artificial unities. The metabolites output since the dilapidation of like polymers is of petite attention. It was recognized that greatest of nano-insecti-cides are ready as nano-suspension. Owing to bio degeneration and conservational influences upsetting these preparations, the nano capsulized insecti-cides may be improved than this preparation.

5. External Damage

Insecticidal dust is usually utilized to defend stowed cereal [41]. In powder collected of nano-organized-alumina (NSA), the instrument depends on bodily disturbance as an alternative of biochemical method of achievement. Established exciting NSA elements desiccate the insect through conferring to those shields through triboelectrically imposes and via superficial part impact sorbs its crude wax coating [42]. Sideways by their aquaphobic performance, these coarse elements similarly reason separations and scrapes on insect forms [43]. Specified that once utilizing insecti-cidal powder, constraints for example particle morphology, superficial part, and particle magnitude have to be factorize in to effect insecticidal effectiveness usefulness [44]. The poisonousness ability to hinge on over the chemical residents. Several nano preparations contain important lubricants (EO), as exhaustive by [45]. In EO-founded-NPs experienced counter to *Rhizopertha dominica* and *Tribolium castaneum*, the remaining interaction poisonousness could be accredited to the late liberation of the vigorous terpenes [46]. Likewise, (E)-anethole, a distinguished constituent of *Pimpinella anisum* (ani-seed) EO is recognized for its insecti-cidal impacts. Once *P. anisum* EO was ready as a

nano-suspension contrary to *T. castaneum*, the shield presented widespread injury in the method of coloring variations, brawny obliteration, width, and mortification in the skin; cellular debris and misplaced difference among the endocuticle and exocuticle [47]. Sideways with epidermal injury, silver nano-elements (Ag-NPs) invented with *Pedalium murex* kernel extractor displayed mane damage since the antenna, cranium, higher and sideways belly in *Aedes egypti* larvae [48]. Monitor alike consequences sideways with the removal of rectal brush and branchias [49].

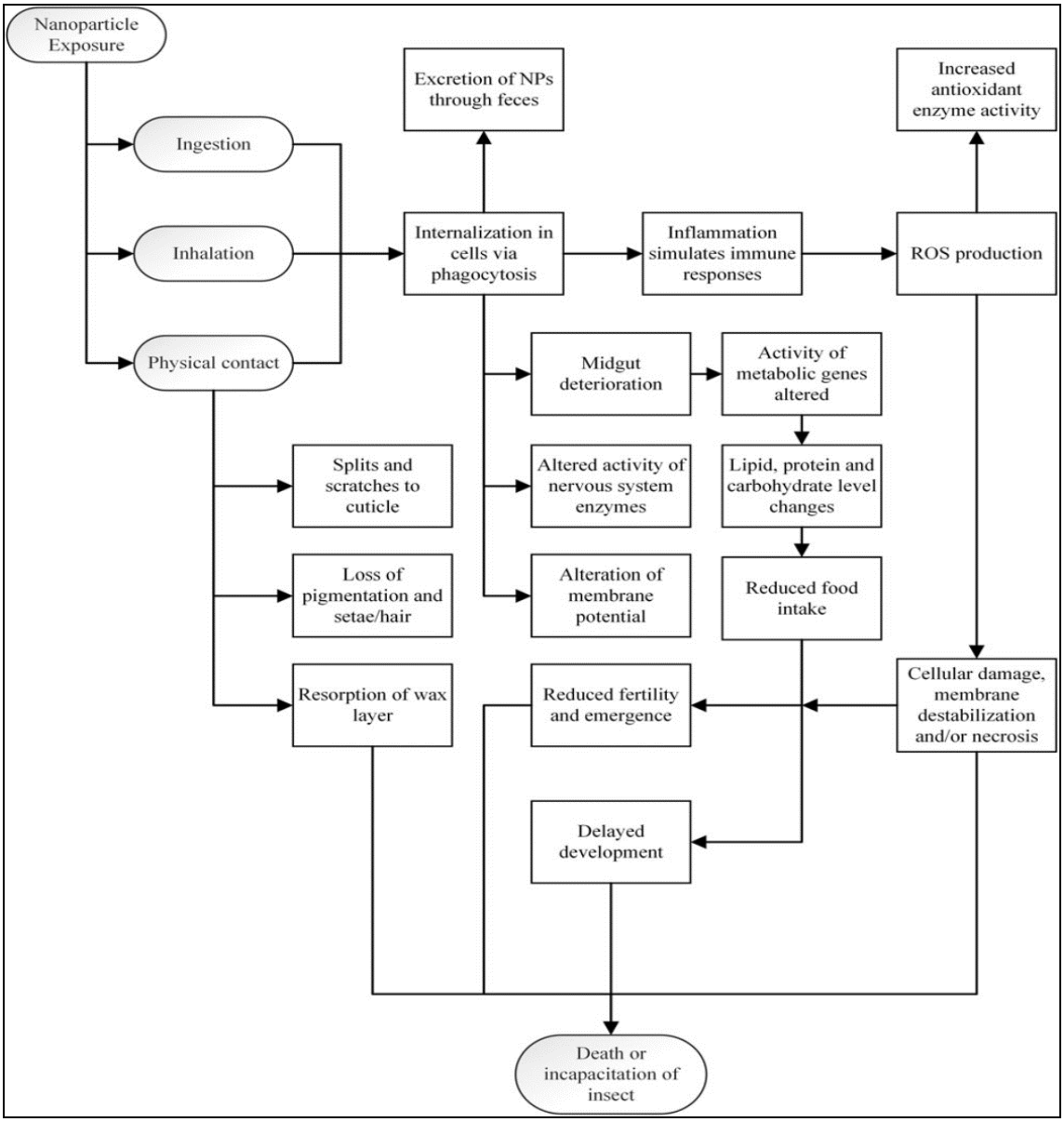

Fig 2: A summary of the numerous biological replies to nano-particle experience inside [50]

Carbon–silver nano mixture by [51] warped the skull and bowels of *Culex quinquefasciatus* and *Anopheles stephensi* black and wounded the regulation of cells and shield sheath; opportunity owing to compulsory among the nano mixture and the attendance of phosphorus and/or sulfur in biotic constructions for example DNA and proteins. In adding, Ag-NPs have similarly been described to reason discoloration of the shield [52, 53, 54 and 55] Thus, the alchemical characteristic of NPs is merely as significant as their sound structure in influencing insects. The impact of NPs at exterior sound structure have been brief in (Figure 2).

6. Influence on reproduction and growth

NPs owning a passive custody ability be dispersed over the form and might continue in ovaries in handled feminine larvae uniform later meta-morphosis [56]. An outline of the impacts of nano-elements on insect-midgut. NMs in fodder minimized female fecundity by disorderly oogenesis and causation disorder in the ovary which passively influences egg placing abilities [57, 58 and 59] although Ag-NPs were monitored to interrupt pupation and appearance also the proportion of male/feminine in *Chironomus riparius* adults [60]. Similarly, fertility was condensed while larval duration and pupation were lengthy in *C. maculatus* afterward handling by Bt-ZnO NPs [61]. In dissimilarity, *Blattella germanica* nymphs unprotected to aero-solized Au-NPs connect maturity previous, nonetheless the capability of ootheca was reduced which the writers hypothesized could be owing to pressure since consumption Au-NPs. The pressure could straight vigor gone since youthful hormone combination thus reduction vitellogenesis. Though the nymphs did not gather an important quantity of golden, the golden contented was established to be 12.7 ± 9.4 lg/g inside adults [62]. In male *Agrius convolvuli*, titanium-

dioxide NPs (TiO2-NPs) or ZnO-NPs decrease semen packages and reduced the mass of testicle although turn into adopted in the vacuoles through phagocytosis [63, 64]. They may likewise confine expansion and reduction germline trunk cells via cumulative RO-S effectiveness in the testis [65].

7. Conclusions

Current works opinions to the refinement and entomolethal possessions of NPs, particularly when swallowed. It seems NPs chiefly performance via the manufacture of ROS who disturb physical roles and induce the invulnerable apparatus, and the physicochemical characteristic of NPs ability impact their method of achievement. A bigger considerate of their machineries at an organismic scale is in demand – mainly on their Geno poisonousness – to define their protection by considerations to nongoal creatures. Here is a deficiency of works associated to the defensive impacts of NPs on insects additional than *B. mori*. Though *B. mori* is frugally significant, more investigate could be passed out on cross-fertilizing species fit in to Lepidoptera, Coleoptera, and Hymenoptera. By information of in what way NPs effort, their possessions ability be enhanced for superior specificity in their manner of achievement which ability chief to negligeable surplus and condensed expenses. However, additional investigate shall generalize nano-insecti-cides in insect administration and rampage insect controller who ability advantage individuals in the extended route.

8. Conflict of Interest

The authors declare no conflict of interest.

9. Acknowledgments

The authors would like to thank Mustansiriyah University (www.uomustansiriyah.edu.iq)Baghdad -Iraq for its support in the present work.

10. References

1. Croft BA. Arthropod biological control agents and pesticides. John Wiley and Sons Inc, 1990.
2. Lucas E, Giroux S, Demougeot S, Duchesne RM, Coderre D. Compatibility of a natural enemy, *Coleomegilla maculata* lengi (Col., Coccinellidae) and four insecticides used against the Colorado potato beetle (Col., Chrysomelidae). Journal of Applied Entomology. 2004 Apr;128(3):233-9.
3. Kah M, Hofmann T. Nanopesticide research: current trends and future priorities. Environment international. 2014 Feb 1;63:224-35.
4. Ojha S, Singh D, Sett A, Chetia H, Kabiraj D, Bora U. Nanotechnology in crop protection. In Nanomaterials in Plants, Algae, and Microorganisms. Academic Press. 2018 Jan 1, 345-391.
5. Johnston HJ, Hutchison GR, Christensen FM, Peters S, Hankin S, Stone V. Identification of the mechanisms that drive the toxicity of TiO 2 particulates: the contribution of physicochemical characteristics. Particle and fiber toxicology. 2009 Dec;6(1):1-27.
6. Malaikozhundan B, Vaseeharan B, Vijayakumar S, Thangaraj MP. *Bacillus thuringiensis* coated zinc oxide nanoparticle and its bio pesticidal effects on the pulse beetle, *Callosobruchus maculatus*. Journal of Photochemistry and Photobiology B: Biology. 2017 Sep 1;174:306-14.
7. Ishwarya R, Vaseeharan B, Subbaiah S, Nazar AK, Govindarajan M, Alharbi NS. Sargassum wightii-synthesized ZnO nanoparticles–from antibacterial and insecticidal activity to immunostimulatory effects on the green tiger shrimp *Penaeus semisulcatus*. Journal of Photochemistry and Photobiology B: Biology. 2018 Jun 1;183:318-30.
8. Pestovsky YS, Martínez-Antonio A. The use of nanoparticles and nano formulations in agriculture. Journal of nanoscience and nanotechnology. 2017 Dec 1;17(12):8699-730.
9. Govindarajan M, Rajeswary M, Muthukumaran U, Hoti SL, Khater HF, Benelli G. Single-step biosynthesis and characterization of silver nanoparticles using *Zornia diphylla* leaves: A potent eco-friendly tool against malaria and arbovirus vectors. Journal of Photochemistry and Photobiology B: Biology. 2016 Aug 1;161:482-9.
10. Malaikozhundan B, Vinodhini J. Nanopesticidal effects of *Pongamia pinnata* leaf extract coated zinc oxide nanoparticle against the Pulse beetle, *Callosobruchus maculatus*. Materials Today Communications. 2018 Mar 1;14:106-15.
11. Baruah S, Dutta J. Nanotechnology applications in pollution sensing and degradation in agriculture: A review. Environmental Chemistry Letters. 2009 Sep;7(3):191-204.
12. Li ZZ, Xu SA, Wen LX, Liu F, Liu AQ, Wang Q, Sun HY, Yu W, Chen JF. Controlled release of avermectin from porous hollow silica nanoparticles: Influence of shell thickness on loading efficiency, UV-shielding property and release. Journal of Controlled Release. 2006 Mar 10;111(1-2):81-8.
13. Wen LX, Li ZZ, Zou HK, Liu AQ, Chen JF. Controlled release of avermectin from porous hollow silica nanoparticles. Pest Management Science: formerly Pesticide Science. 2005 Jun;61(6):583-90.
14. Wang L, Li X, Zhang G, Dong J, Eastoe J. Oil-in-water nanoemulsions for pesticide formulations. Journal of colloid and interface science. 2007 Oct 1;314(1):230-5.
15. Guan H, Chi D, Yu J, Li X. A novel photodegradable insecticide: Preparation, characterization and properties evaluation of nano-Imidacloprid. Pesticide Biochemistry and Physiology. 2008 Oct 1;92(2):83-91.
16. Guan H, Chi D, Yu J, Li H. Dynamics of residues from a novel nano-imidacloprid formulation in soyabean fields. Crop protection. 2010 Sep 1;29(9):942-6.
17. Sooresh A, Kwon H, Taylor R, Pietrantonio P, Pine M, Sayes CM. Surface functionalization of silver nanoparticles: Novel applications for insect vector control. ACS applied materials & interfaces. 2011 Oct 26;3(10):3779-87.
18. Kang MA, Seo MJ, Hwang IC, Jang C, Park HJ, Yu YM, Youn YN. Insecticidal activity and feeding behavior of the green peach aphid, *Myzus persicae*, after treatment with nano types of pyrifluquinazon. Journal of Asia-Pacific Entomology. 2012 Dec 1;15(4):533-41.
19. Xin JH, Bin F, inventors; Hong Kong Polytechnic University HKPU, assignee. Insect repellant fabrics having nano capsules with insecticide. United States patent US 8,956,634. 2015 Feb 17.

20. Yang W, He K, Zhang J, Guo S. pH-controlled *Bacillus thuringiensis* Cry1Ac protoxin loading and release from polyelectrolyte microcapsules.
21. Ziaee M, Hamzavi F. Application of nanoparticles in pest management programs-a review. In International Conference on Green Agro-Industry (ICGAI). 2013 Nov 12, 386-393.
22. Feng BH, Peng LF. Synthesis and characterization of carboxymethyl chitosan carrying ricin oleic functions as an emulsifier for azadirachtin. Carbohydrate polymers. 2012 Apr 2;88(2):576-82.
23. Zhang J, Li M, Fan T, Xu Q, Wu Y, Chen C, Huang Q. Construction of novel amphiphilic chitosan copolymer nanoparticles for chlorpyrifos delivery. Journal of Polymer Research. 2013 Mar;20(3):1-1.
24. Lu W, Lu ML, Zhang QP, Tian YQ, Zhang ZX, Xu HH. Octa hydrogenated retinoic acid-conjugated glycol chitosan nanoparticles as a novel carrier of azadirachtin: Synthesis, characterization, and *in vitro* evaluation. Journal of Polymer Science Part A: Polymer Chemistry. 2013 Sep 15;51(18):3932-40.
25. Campos EV, Proença PL, Oliveira JL, Melville CC, Della Vechia JF, De Andrade DJ. Chitosan nanoparticles functionalized with β-cyclodextrin: A promising carrier for botanical pesticides. Scientific reports. 2018 Feb 1;8(1):1-5.
26. Wang Y, Cui H, Sun C, Zhao X, Cui B. Construction and evaluation of controlled-release delivery system of Abamectin using porous silica nanoparticles as carriers. Nanoscale research letters. 2014 Dec;9(1):1-6.
27. Liu X, He B, Xu Z, Yin M, Yang W, Zhang H. A functionalized fluorescent dendrimer as a pesticide nanocarrier: application in pest control. Nanoscale. 2015;7(2):445-9.
28. Nguyen TN, Hua QC, Nguyen TT. Enhancing insecticide activity of anacardic acid by intercalating it into MgAl layered double hydroxides nanoparticles. Journal of Vietnamese Environment. 2014 Nov 5;6(3):208-11.
29. Lai F, Wissing SA, Müller RH, Fadda AM. *Artemisia arborescens* L essential oil-loaded solid lipid nanoparticles for potential agricultural application: preparation and characterization. Asps Pharm SciTech. 2006 Mar;7(1): E10-8.
30. Yang FL, Li XG, Zhu F, Lei CL. 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. 2009 Nov 11;57(21):10156-62.
31. Rani PU, Madhusudhanamurthy J, Sreedhar B. Dynamic adsorption of α-pinene and linalool on silica nanoparticles for enhanced antifeedant activity against agricultural pests. Journal of pest science. 2014 Mar;87(1):191-200.
32. Qian K, Shi T, Tang T, Zhang S, Liu X, Cao Y. Preparation and characterization of nano-sized calcium carbonate as controlled release pesticide carrier for validamycin against *Rhizoctonia solani*. Microchemical Acta. 2011 Apr 1;173(1-2):51-7.
33. Song MR, Cui SM, Gao F, Liu YR, Fan CL, Lei TQ, Liu DC. Dispersible silica nanoparticles as carrier for enhanced bioactivity of chlorfenapyr. Journal of Pesticide Science. 2012: D12-027.
34. Wibowo D, Zhao CX, Peters BC, Middelberg AP. Sustained release of fipronil insecticide *in vitro* and *in vivo* from biocompatible silica nano capsules. Journal of agricultural and food chemistry. 2014 Dec 31;62(52):12504-11.
35. Jenne M, Kambham M, Tollamadugu NP, Karanam HP, Tirupati MK, Balam RR. The use of slow releasing nanoparticle encapsulated Azadirachtin formulations for the management of *Caryedon serratus* O. (groundnut bruchid). IET nanobiotechnology. 2018 Sep 27;12(7):963-7.
36. Meredith AN, Harper B, Harper SL. The influence of size on the toxicity of an encapsulated pesticide: a comparison of micron-and nano-sized capsules. Environment international. 2016 Jan 1;86:68-74.
37. Oliveira JL, Campos EV, Pereira AE, Pasquoto T, Lima R, Grillo R. Zein nanoparticles as eco-friendly carrier systems for botanical repellents aiming sustainable agriculture. Journal of agricultural and food chemistry. 2018 Feb 14;66(6):1330-40.
38. Praveen Kumar G, Divya A. Nanoemulsion based targeting in cancer therapeutics. Med Chem. 2015;5(5):272-84.
39. Soppimath KS, Aminabhavi TM, Kulkarni AR, Rudzinski WE. Biodegradable polymeric nanoparticles as drug delivery devices. Journal of controlled release. 2001 Jan 29;70(1-2):1-20.
40. Gao Y, Ding X, Zheng Z, Cheng X, Peng Y. Template-free method to prepare polymer nanocapsules embedded with noble metal nanoparticles. Chemical communications. 2007 Sep 12(36):3720-2.
41. Hagstrum DW, Phillips TW. Evolution of stored-product entomology: protecting the world food supply. Annual review of entomology. 2017 Jan 31;62:379-97.
42. 42- Stadler T, Lopez Garcia GP, Gitto JG, Buteler M. Nanostructured alumina: biocidal properties and mechanism of action of a novel insecticide powder. Bull. Insectol. 2017 Jun 1;70(1):17-25.
43. Arumugam G, Velayutham V, Shanmugavel S, Sundaram J. Efficacy of nanostructured silica as a stored pulse protector against the infestation of bruchid beetle, *Callosobruchus maculatus* (Coleoptera: Bruchidae). Applied nanoscience. 2016 Mar 1;6(3):445-50.
44. Buteler M, Sofie SW, Weaver DK, Driscoll D, Muretta J, Stadler T. Development of nano alumina dust as insecticide against *Sitophilus oryzae* and *Rhyzopertha dominica*. International journal of pest management. 2015 Jan 2;61(1):80-9.
45. Mossa AT. Green pesticides: Essential oils as biopesticides in insect-pest management. Journal of environmental science and technology. 2016 Sep 1;9(5):354.
46. González JO, Gutiérrez MM, Ferrero AA, Band BF. Essential oils nanoformulations for stored-product pest control–Characterization and biological properties. Chemosphere. 2014 Apr 1;100:130-8.
47. Hashem AS, Awadalla SS, Zayed GM, Maggi F, Benelli G. Pimpinella anisum essential oil nanoemulsions against *Tribolium castaneum*—insecticidal activity and mode of action. Environmental Science and Pollution Research. 2018 Jul;25(19):18802-12.

48. Ishwarya R, Vaseeharan B, Anuradha R, Rekha R, Govindarajan M, Alharbi NS. Eco-friendly fabrication of Ag nanostructures using the seed extract of *Pedalium murex*, an ancient Indian medicinal plant: Histopathological effects on the Zika virus vector *Aedes aegypti* and inhibition of biofilm-forming pathogenic bacteria. Journal of Photochemistry and Photobiology B: Biology. 2017 Sep 1;174:133-43.
49. Banumathi B, Vaseeharan B, Ishwarya R, Govindarajan M, Alharbi NS, Kadaikunnan S. Toxicity of herbal extracts used in ethno-veterinary medicine and green-encapsulated ZnO nanoparticles against *Aedes aegypti* and microbial pathogens. Parasitology research. 2017 Jun;116(6):1637-51.
50. Shahzad K, Manzoor F. Nano formulations and their mode of action in insects: a review of biological interactions. Drug and chemical toxicology. 2021 Jan 2;44(1):1-1.
51. Sultana N, Raul PK, Goswami D, Das B, Gogoi HK, Raju PS. Nano weapon: Control of mosquito breeding using carbon-dot-silver nanohybrid as a bio larvicide. Environmental Chemistry Letters. 2018 Sep;16(3):1017-23.
52. Posgai R, Cipolla-McCulloch CB, Murphy KR, Hussain SM, Rowe JJ, Nielsen MG. Differential toxicity of silver and titanium dioxide nanoparticles on *Drosophila melanogaster* development, reproductive effort, and viability: Size, coatings and antioxidants matter. Chemosphere. 2011 Sep 1;85(1):34-42.
53. Armstrong N, Ramamoorthy M, Lyon D, Jones K, Duttaroy A. Mechanism of silver nanoparticles action on insect pigmentation reveals intervention of copper homeostasis. PLoS One. 2013 Jan 7;8(1): e53186.
54. Ávalos A, Haza AI, Drosopoulou E, Mavragani-Tsipidou P, Morales P. *In vivo* genotoxicity assessment of silver nanoparticles of different sizes by the Somatic Mutation and Recombination Test (SMART) on Drosophila. Food and Chemical Toxicology. 2015 Nov 1;85:114-9.
55. Al-Naami MT, Mahmood EA, Mohammad HE. The effect of silver nanoparticles on second larval instar of *Trogoderma granarium* everts (Insecta: Coleoptera: Dermestidae). International Journal of Science and Nature. 2017;8(2):303-6.
56. Phanse Y, Dunphy BM, Perry JL, Airs PM, Paquette CC, Carlson JO, et al. Biodistribution and toxicity studies of print hydrogel nanoparticles in mosquito larvae and cells. PLoS neglected tropical diseases. 2015 May 21;9(5):e0003735.
57. Chen H, Wang B, Feng W, Du W, Ouyang H, Chai Z. Oral magnetite nanoparticles disturb the development of *Drosophila melanogaster* from oogenesis to adult emergence. Nanotoxicology. 2015 Apr 3;9(3):302-12.
58. Raj A, Shah P, Agrawal N. Dose-dependent effect of silver nanoparticles (AgNPs) on fertility and survival of Drosophila: An in-vivo study. PLoS One. 2017 May 24;12(5): e0178051.
59. Wu VM, Uskoković V. Population effects of calcium phosphate nanoparticles in *Drosophila melanogaster*: the effects of phase composition, crystallinity, and the pathway of formation. ACS biomaterials science & engineering. 2017 Oct 9;3(10):2348-57.
60. Nair PM, Choi J. Identification, characterization and expression profiles of *Chironomus riparius* glutathione S-transferase (GST) genes in response to cadmium and silver nanoparticles exposure. Aquatic toxicology. 2011 Feb 1;101(3-4):550-60.
61. Malaikozhundan B, Vaseeharan B, Vijayakumar S, Thangaraj MP. *Bacillus thuringiensis* coated zinc oxide nanoparticle and its biopesticidal effects on the pulse beetle, *Callosobruchus maculatus*. Journal of Photochemistry and Photobiology B: Biology. 2017 Sep 1;174:306-14.
62. Small T, Ochoa-Zapater MA, Gallello G, Ribera A, Romero FM, Torreblanca A. Gold-nanoparticles ingestion disrupts reproduction and development in the German cockroach. Science of The Total Environment. 2016 Sep 15;565:882-8.
63. Pompa PP, Vecchio G, Galeone A, Brunetti V, Sabella S, Maiorano G. *In vivo* toxicity assessment of gold nanoparticles in *Drosophila melanogaster*. Nano Research. 2011 Apr 1;4(4):405-13.
64. Kubo-Irie M, Shimoda M, Sato A, Shida K, Yamaguchi T, Mohri H. Effect of nanoparticles injected into larvae on spermatogenesis in the pupal testis of the sweet potato hornworm, *Agrius convolvuli* (L.). Fundamental Toxicological Sciences. 2015 Jan 13;2(1):1-8.
65. Ong C, Lee QY, Cai Y, Liu X, Ding J, Yung LY. Silver nanoparticles disrupt germline stem cell maintenance in the Drosophila testis. Scientific reports. 2016 Feb 5;6(1):1-0.