

# Green Nanobiopesticide used in Integrated Pest Management: A Review

Priya Tetwar<sup>1</sup>, Dr. Archana Masram<sup>2</sup>

<sup>1</sup>Department of Zoology, RTM Nagpur University, Nagpur, Maharashtra, India

<sup>2</sup>Department of Zoology, L.A.D. & Smt. R.P. College for Women, Nagpur, Maharashtra, India

doi.org/10.64643/IJIRTV12I9-193243-459

**Abstract-** The economy of developing countries heavily relies on the agriculture sector as its foundation. Researchers in the field of pest control are now concentrating on creating non-toxic options to decrease our dependence on chemical insecticides for controlling pests and diseases. Today, nanotechnology offers sustainable and eco-friendly solutions for managing insects and pests in agriculture, thereby boosting crop production efficiently. The biosynthesis of nanoparticles by utilizing various plant sources, such as leaves, stems, and fruits is a green and eco-friendly technology. This review highlights various metallic and metal oxide nanoparticles synthesis and their applications in integrated pest management. Nanotechnology research in agriculture is in its early stages but progressing rapidly. Educating farmers and the public about the benefits and safe use of nanobiopesticides will be essential for their successful adoption. Nanotechnology has been shown to be a powerful tool for creating novel nanocomposites to prevent pests and enhance crop varieties.

**Keywords:** biological synthesis, green synthesis, nanobiopesticide, nanoparticles, nanotechnology, insecticide.

## I. INTRODUCTION

India is an agricultural nation with more than 80% of the population employed in agriculture. Many crops has been negatively affected by pests and cause 15–20% yield losses annually [1]. Controlling pests and diseases in farming often heavily depend on chemical pesticides. Repeatedly use can make insects more resistant to them. Furthermore, the excess use of chemical pesticides shows harmful effects on the environment and even the crops themselves. When these pesticides are not used properly in agriculture, they can lead to increased pollution in the environment, which is not good for human health [2].

Some researchers in pest control are shifting their focus towards developing non-toxic alternatives to reduce our reliance on chemical insecticides for

managing pests and diseases. Two promising recent approaches in this regard are biopesticides and nanopesticides [3]. Both biopesticides and nanopesticides represent innovative approaches to pest control that aim to address the limitations and environmental concerns associated with traditional chemical insecticides. These alternatives align with the growing emphasis on sustainable and eco-friendly agricultural practices [3,4].

Biopesticides are a class of pest management agents that are sourced from natural substances, including animals, plants, bacteria, and specific minerals. [5]. Biopesticide have been shown to be effective for pest management and minimize damage to crops and the generation of sustainable agricultural products [6]. The majority of biopesticide have limitations like short-lived effectiveness and low stability; Hence, addressing these challenges necessitates the development of new pest control strategies through the adoption of advanced and innovative technologies for pest management [7]. Nanotechnology is an emerging approach for delivering and applying pesticides, and its use is growing in importance within agriculture and the food sector [2].

Various techniques are described for the nanoparticles synthesis. The physical and chemical processes for synthesizing nanoparticles are not only expensive but also environmentally damaging. In order to minimize the use of harmful organic solvents, researchers have been actively investigating environmentally friendly methods for nanoparticle synthesis [8,9]. The biological synthesis of nanoparticles (NPs) shows the ability to produce NPs with excellent polydispersity, dimensions, and stability. These biologically synthesized nanoparticles such as silver, nickel, cobalt, zinc and copper used for pest control known as “nanobiopesticides” [4]. While nanobiopesticides currently represent a minor segment of the overall

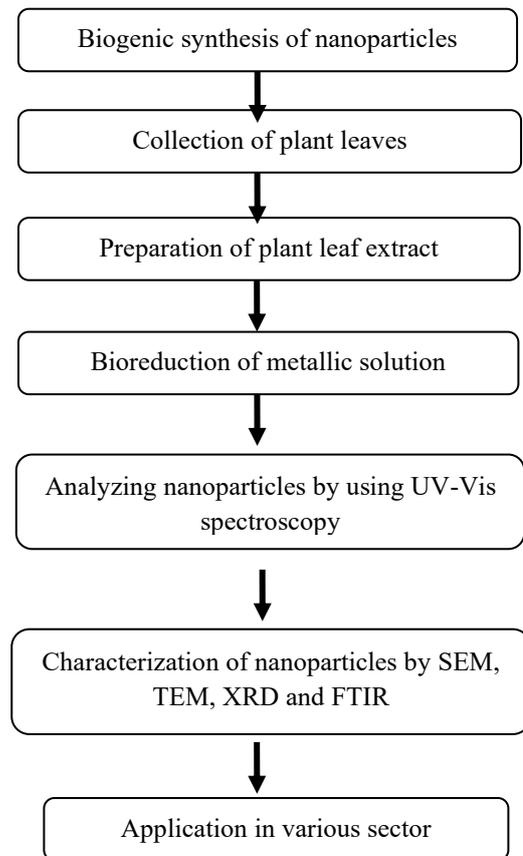
pesticide market, the concerns associated with chemical pesticides have created an opportunity for the rise of nanobiopesticides. Farmers are increasingly adopting this technology for purposes such as promoting proper plant growth, diagnosing plant diseases, improving crop varieties and controlling pests [5,6,7]. Due to capping and reducing properties of biosynthesized metal/metal oxide nanoparticles (NPs). This eco-friendly synthesis method is sustainable and enables the production of desired nanoparticles in various sizes and shapes by adjusting parameters during the synthesis process [10]. The antiviral, antifungal, antibacterial, and anticancer properties of biosynthesized nanoparticles, along with their impact on plant growth, nutrition, and defense mechanisms, were examined [11].

Currently, there is no conclusive evidence of the harmful effects of nanotechnology on the environment. However, it's important to note that nanotechnology is an evolving field of study and many countries around the world have recognized the potential of nanotechnology in the agriculture and food sector and have made substantial investments in its research and development [12]. Additionally, equal attention is being given to addressing societal issues associated with nanotechnology and to enhancing public awareness and understanding of its implications. This cautious and proactive approach aims to ensure the safe and responsible use of nanotechnology in agriculture and other sectors [5].

## II. NANOPARTICLES

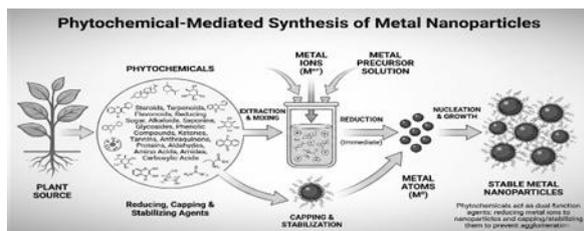
Nanotechnology is becoming a highly promising research area for developing new active ingredients with nanoscale sizes, as well as their formulation and delivery, collectively known as "nanopesticides." Nanotechnological methods have been used for either the "green" synthesis of active nanomaterials with antimicrobial, antifungal, and antiparasitic properties or for creating stable biopesticide nano-formulations with prolonged effects [2,7]. Nanomaterials are characterized by their unique surface properties, small size (ranging from 1 to 100 nanometers), and large surface area [6,13].

## III. BIOSYNTHESIS OF NANOPARTICLES



## IV. ROLE OF PLANTS IN GREEN SYNTHESIS OF NANOPARTICLES

The phytochemicals present in the plants are identified as steroids, terpenoids, flavonoids, reducing sugar, alkaloids, saponins, glycosides, phenolic compounds, ketones, tannins, anthraquinone, proteins, aldehydes, amino acids, amides and carboxylic acids [14] which were responsible for immediate reduction of metal into metal nanoparticles [15,16]. It was found that these reducing components also served as capping and stabilizing agents [17]. The presence of phytochemicals that contributed to the reduction and stabilization was also confirmed by the phytochemical analysis of the plant extract and studied by FTIR [17,18,19].



## V. TYPES OF NANOPARTICLES

A diverse range of nanoparticles are synthesized using eco-friendly method and characterized through various techniques.

### 5.1 Copper and Copper oxide Nanoparticles (Cu and CuO NPs)

Spherical CuO NPs were synthesized by using *Tabernaemontana* and characterized by UV-Vis absorption spectroscopy, Fourier transform infrared spectroscopy (FT-IR), X-ray diffraction (XRD), scanning electron microscopy (SEM) with energy dispersive X-ray analysis (EDX) and transmission electron microscopy (TEM) analysis. FT-IR also confirmed the presence of functional groups. The antimicrobial activity of biogenic CuO NPs was investigated against urinary tract pathogens [20]. Using leaf extract of *P. acerifolium* CuO NPs were successfully synthesized and confirmed by UV-Vis spectra and absorption peak was observed at 383 nm. SEM revealed that CuO NPs have a diameter ranging from 0.1 to 0.25  $\mu\text{m}$  and oval shaped [21]. CuNPs were synthesized from the aqueous extract of *Orobancha aegyptiaca* [22] and from the leaf broth of *Azadirachta indica* [15]. The XRD pattern shows a high degree of crystallinity of the sample. SEM and TEM analyzed spherical and cubical shape of the CuNPs with particle sizes less than 50 nm and highly stable [22]. The plant biomolecules facilitate the reduction of  $\text{Cu}^{2+}$  ions to CuNPs and also function as a capping and stabilizing agent. The pH 6.6 and 85°C temperatures are favorable for the biosynthesis of CuNPs [15].

Biosynthesis of stable CuNPs was done by using aqueous leaf extract of *Nerium oleander* and *Jatropha curcas*. The size of the CuNPs obtained was in the range of 3.47 nm to 15.2 nm and formation was confirmed from the peak at 390 nm [16,18]. The *A. scholaris* leaves extracts and *Ocimum sanctum* leaf extract synthesized Cu-NPs was confirmed by a color transition from light green to dark green and eventually to dark brown, with UV-vis analysis indicating a stable wavelength of 243 nm for their formation. In SEM analysis

presence of triangular, cylindrical, polygonal, and nearly spherical shapes indicates the CuNPs formation [14,23]. CuNPs were successfully synthesized using *Acacia cornigera* with size of 63–153 nm and *Anona purpurea* extract with 87–193 nm [24].

CuO NPs synthesized using aqueous leaf extract of *Tecoma castanifolia* and characterized by TEM analysis which shows a size of less than 100 nm and a spherical shape. EDAX analysis confirmed the elemental composition of the CuO NPs [25]. Synthesized CuO NPs by *Carica papaya* leaves extract were rod in shape and had a mean particle size of 140 nm, FTIR spectroscopy results analyzed the presence of bioactive functional groups, while X-ray diffraction (XRD) spectra confirmed the crystalline nature of CuO NPs [26].

CuONPs synthesized using leaves of *Azadirachta indica*, *Solanum lycopersicum*, *Prunus domestica*, *Malus domestica* and *Morinda citrifolia* plants. TEM analysis shows crystalline structure and  $36 \pm 8$  nm size and spherical shape [19,27,28,29,30].

### 5.2 Silver nanoparticles (Ag NPs)

The essential components for the green synthesis of AgNPs are a silver metal ion solution and a biological reducing agent. The simplest and most cost-effective method for producing AgNPs involves the reduction and stabilization of silver ions through the combination of biomolecules like polysaccharides, saponins, vitamins, alkaloids, amino acids, phenols, proteins and terpenes [31]. Using *Artemisia herba-alba* plant extract, AgNPs were synthesized, resulting in spherical particles ranging from 9.68 to 36.7 nm. The synthesized AgNPs exhibited a maximum absorption peak at 430 nm [32].

The larvicidal activity of green-synthesized AgNPs against the cotton pest *Spodoptera littoralis* larvae was evaluated using both feeding and contact application methods. [32]. Different concentrations of AgNPs were tested on cowpea seed beetle, *C. maculatus*. AgNPs was highly effective on adults and larvae with 100% and 83% mortality [33].

### 5.3 Silica nanoparticles (Si NPs)

Si NPs were produced by a biological method using *Punica granatum* leaf extract and Tetra Ethyl Ortho Silicate and characterized by XRD, SEM, EDX, and FTIR. All the characterizations revealed that the particles were an amorphous in nature with spherical

in shape and an average size of 12 nm. The absorption spectra of Si NPs were observed to range from 300 to 370 nm [34]. It was also synthesized using local agricultural waste, sugarcane bagasse [35].

Nano-silica (SiO<sub>2</sub>) NPs synthesized by green synthesis method *Rhus coriaria* L. extract with sodium metasilicate. They were characterized using FTIR, UV-Vis Spectroscopy, XRD, and FESEM [36].

Silica nanoparticles were synthesized from *P. granatum* which evaluated antibacterial activity using the well diffusion method. The antibacterial studies demonstrated that *P. granatum* assisted silica nanoparticles possess strong antibacterial properties [34].

#### 5.4 Magnesium oxide nanoparticles (MgO-NPs)

The synthesized MgO-NPs from Brown algae, *Cystoseira crinita*, were characterized by UV-vis, FTIR, TEM, SEM, XRD, EDX, and X-ray photoelectron spectroscopy (XPS). The nanoparticles exhibited promising antibacterial activity as well as used against *Candida albica*. Additionally, they demonstrated larvicidal and pupicidal effects against *Musca domestica* [37].

Magnesium nanoparticles (MgNPs) were synthesized using *Rosa foribunda* charisma petals. HR-TEM images revealed polyhedral shapes and sizes ranging from 35.25 to 55.14 nm. MgNPs demonstrated excellent anti-aging activity and showed promising antibacterial effects against three skin pathogens: *Staphylococcus epidermidis*, *Streptococcus pyogenes*, and *Pseudomonas aeruginosa*. MgNPs have the potential to serve as a valuable natural ingredient in the skin care cosmetics industry [38].

*Amaranthus blitum*, *Andrographis paniculata* and *Amaranthus tricolor* leaf extracts from these plants were used to synthesize of MgO NPs. FTIR spectroscopy and TEM analyze and identify the functional groups in the extracts, showing stability. The absorbance at 320 nm in the UV-visible spectrum indicates the formation of metal oxide in the sample [39].

Using *Annona squamosa* seeds and *Tecoma stans* (L.) flower extracts MgONPs were synthesized successfully in an eco-friendly mode and characterized by UV-vis, XRD, EDX, SEM and TEM. The absorption spectra of MgONPs were found to be 281 nm. It also shows antibacterial activity [40,41]. MgO NPs were synthesized using *Alstonia scholaris* leaf extract and characterized using SEM, XRD, and EDX techniques. The crystallite size of MgONPs was found to be 19.57 nm [42].

#### 5.5 Nickel oxide nanoparticles (NiO NPs)

Biosynthesized NiO-NPs using *Ocimum sanctum* and *Acacia nilotica* leaf extract, were characterized by SEM, TEM, FTIR, UV-Vis spectroscopy, and XRD. The antibacterial potential, electrochemical properties, and hemolytic effects of the NPs were also investigated. XRD patterns showed that NiO NPs had face-centered cubic structures and exhibited a high degree of crystallinity [43,44].

Phyto-synthesized NiO nanoparticles by using *Catharanthus roseus* and *Rauwolfia serpentine* plant leaf extract. By using agar diffusion method (ADM) antibacterial properties were also examined against different bacteria [45]. NiO NPs were tested against *Callosobruchus maculatus* [46]. NiO-NPs caused physiological and histological changes in the ground beetle *B. polychresta* studied [47].

Table I: Showing Biosynthesized Nanoparticles

Reducing agent	Synthesis pathway	Metal	Target	References
<i>Orobancha aegyptiaca</i>	Dried stems	Cu NPs	<i>Meloidogyne incognita</i>	[22]
<i>Solanum lycopersicum</i>	leaf extract	CuONPs	Antibacterial activity	[19]
<i>Prunus domestica</i>	leaf extract	CuONPs	Biodiesel blend preparation	[28]
<i>Azadirachta indica</i>	leaf extract	CuONPs	Anticancer drug (ROS)	[27]
<i>Jatropha curcas</i>	leaf extract	Cu NPs	photocatalytic activity against dyes	[18]
<i>Tecoma castanifolia</i>	leaf extract	Cu NPs	<i>E.coli</i> and <i>S. aureus</i>	[25]
<i>Malus domestica</i>	leaf extract	CuONPs	Antibacterial activity	[29]
polyol process	polyol process	Cu NPs	<i>Anopheles</i> , <i>Culex</i> , <i>Rhipicephalus</i>	[48]
<i>Ocimum sanctum</i>	leaves extracts	Cu NPs		[23]
<i>Alstonia scholaris</i>	leaves extracts	Cu NPs	<i>Escherichia coli</i> and <i>Staphylococcus aureus</i>	[14]
<i>Morinda citrifolia</i>	leaf extract	CuONPs	Antibacterial activity	[30]
seedless dates	seedless dates	Cu/CuO NPs		[17]
<i>Azadirachta indica</i>	leaves extract	Cu NPs		[15]
<i>Pterospermum acerifolium</i>	leaves extracts	Cu ONPs	water flea <i>Daphnia</i>	[21]

<i>Carica papaya</i>	leaf extract	CuONPs		[26]
<i>Tabernaemontana divaricate</i>	leaf extract	CuONPs	<i>Escherichia coli</i>	[20]
<i>Acacia cornigera and Annona purpurea</i>	plants extracts	Cu NPs	<i>Tribolium castaneum</i>	[24]
<i>Nerium oleander</i>	leaf extract	Cu NPs	Antibacterial activity	[16]
<i>Artemisia herba-alba</i>	plant extract	Ag	<i>Spodoptera littoralis</i>	[32]
<i>Tagetes erecta</i>	leaves extract	Ag	<i>Escherichia coli</i> and <i>Staphylococcus aureus</i>	[50]
<i>Capparis zeylanica</i>	leaves extract	Ag	<i>E-coli, Pseudomonas aeruginosa</i>	[49]
Solvothermal method	Chemical	Ag	cowpea seed beetle, <i>C. maculatus</i>	[33]
Sugarcane bagasse	Agricultural waste	Si NPs		[35]
<i>Punica granatum</i>	leaf extract	Si NPs	<i>E. coli</i> and <i>Salmonella</i> sp.	[34]
<i>Rhus coriaria</i>	leaf extract	SiO <sub>2</sub> NPs		[36]
<i>Cystoseira crinita</i>	brown algae	MgO NPs	<i>Musca domestica</i>	[37]
<i>Amaranthus tricolor</i>	leaf extract	MgO NPs	Biosensing and therapeutic development	[39]
<i>Tecoma stans</i>	leaf extract	MgO NPs		[41]
<i>Alstonia scholaris</i>	leaf extract	MgO NPs	Anti-inflammatory activity	[42]
<i>Annona squamosa</i>	seeds	MgO NPs	Antibacterial activity	[40]
<i>Rosa foribunda</i>	charisma petals	Mg NPs	<i>Staphylococcus, Streptococcus</i> and <i>Pseudomonas</i>	[38]
<i>Catharanthus roseus</i>	leaf extract	NiONPs	<i>E. coli, Pseudomonas</i> spp. And <i>Bacillus</i> spp.	[45]
<i>Acacia nilotica</i>	leaf extract	NiONPs	Antibacterial activity <i>B. subtilis</i>	[43]
<i>Ocimum sanctum</i>	leaf extract	NiNPs	treat textile and tannery effluents.	[44]
<i>Rauvolfia serpentine</i>	leaf extract	NiONPs	<i>Callosobruchus maculatus</i>	[46]

## VI. INSECTICIDAL ACTIVITY OF NANOBIOPESTICIDES

The CuNPs from *Acacia cornigera* showed 90% mortality effective insecticidal activity against *Tribolium castaneum*, a pest of stored grain and CuNPs from obtained *A. purpurea* showed 76.6% mortality against *Tribolium castaneum* [24]. The synthesized Cu NPs and copper acetate solution showed larvicidal activity of *Anopheles subpictus*, *Culex quinquefasciatus* and *Rhipicephalus microplus* and also showed anti-parasitic activity [48]. Nematode mortality depended on concentration of NPs and exposure time [22].

CuO NPs used in control and management of crops and vegetables pests. CuO NPs were toxic to *Daphnia* [21]. The strong antibacterial activity reported against Gram-positive bacteria (*Bacillus subtilis*, and *Staphylococcus aureus*), Gram-negative bacteria (*Escherichia coli*) and antifungal activity also analysed [16,19,25,29,30].

Nano-silica in comparison with Silica & Diazinon, was applied as foliar spray on squash plants in the greenhouse and fed to newly hatched *Spodoptera littoralis* larvae [51]. SiNPs efficiently used as essential tool in *S. littoralis* management programs, which showed entomotoxic effect [52]. SiNPs showed effects on larval enzyme activity of second instar larvae of *S. littoralis* [53]. NiO-NPs caused physiological and histological changes in the ground beetle *B. polychresta* and *Callosobruchus maculatus* were studied [46,47].

MgO NPs used against *Musca domestica* which showed larvicidal and pupicidal activity [37]. Different concentrations of silica and silver nanoparticles were synthesized by solvothermal method and tested on *C. maculatus*. The LC<sub>50</sub> value for Si NPs was calculated as 1.03 g kg<sup>-1</sup> on larvae and for Ag NPs was calculated as 1.00 g kg<sup>-1</sup> on larvae, respectively. Result showed that, the both nanoparticles were highly effective on adults with 100% and larvae with 83% mortality, respectively [33].

Using *Eriobotrya japonica* leaf extract Zinc Oxide Nanoparticles (ZnO-NPs) were synthesized and evaluates their insecticidal and antibacterial properties. which showed significant efficacy against stored grain pests like *Sitophilus oryzae* and *Tribolium castaneum*, as well as against bacterial strains such as *Ralstonia solanacearum*. The findings suggest that these eco-friendly nanoparticles could serve as effective protective agents for seeds and stored grains, promoting sustainable agricultural practices [54].

## VII. MORPHOLOGICAL AND HISTOPATHOLOGICAL CHANGES AFTER TREATMENT

Ar-AgNP-infected larvae stopped feeding and showed decolorization of the cuticle in the thoracic region. These studies investigated changes in the histological structure in midgut epithelial cells, the cuticle, and different larval tissues [32]. 2<sup>nd</sup> larval

instar of *Spodoptera* treated by Dimilin 48% compound and mid gut section of larvae showed alterations in cell size and shape, mid-gut epithelial cell vacuolization. Nuclei and brush border degenerations, peritrophic membrane separation and swelling in gut-lumen these effects showed by 4th larval instar of *Spodoptera* after the treatment of Emafel 4% [55].

The morphological changes observed in the deceased sixth-instar larvae of treated *Spodoptera littoralis* included pupal malformation, pupation, and adult emergence. Additionally, biological aspects such as mortality due to digestive tract impairment, surface enlargement of the integument, dehydration, blockage of spiracles and tracheae, reduction in body weight, and protein degradation were investigated. Deficiency in protein, carbohydrates, and lipid content were reported after treating SiO<sub>2</sub>-TX, SiO<sub>2</sub>-CTAB, and SiO<sub>2</sub>-PVP in sixth instars of *S. littoralis* [52]. Sections of the gut region of treated larvae showed disruption of gut layers and gut musculature, elongation of epithelial cells or form projections towards the lumen. Trachea, fat bodies, and gonads were affected [32].

#### VIII. CONCLUSION

Improper management, mishandling, or lack of adequate knowledge can result in the misuse and overuse of chemical pesticides, causing harm and accumulation in areas beyond the targeted crops. This negatively affects beneficial organisms like microorganisms, plants, and small animals.

Exposure to pesticides can lead to acute reactions in humans, including headaches, sneezing, irritation, vomiting and skin rashes. The severity of these effects depends on the duration and concentration of exposure. Chemical pesticides can generate more toxic compounds, making these processes both harmful and expensive. Adopting eco-friendly solutions like nanobiopesticides is recommended to promote a sustainable environment and maintain a healthy, productive ecosystem. Although nanobiopesticides currently make up a small portion of the pesticide market, farmers are increasingly using this technology to support plant growth, diagnose plant diseases, and manage pests.

The eco-friendly approach of nanoparticle synthesis not only reduces the environmental impact associated with traditional chemical methods but also leverages the natural properties of plants to produce nanoparticles with unique characteristics. The synthesized nanoparticles, such as silver,

copper, nickel, gold, zinc, etc. exhibit promising antimicrobial, antioxidant, and anti-inflammatory activities, making them suitable for various biomedical applications, including drug delivery and wound healing. Overall, the findings emphasize the potential of utilizing agricultural waste and natural resources in nanotechnology, creating the way for sustainable practices in the field. The review encourages further research to explore the full capabilities of these green synthesized nanoparticles, which could lead to innovative solutions in healthcare, environmental, and pest management.

#### IX. ACKNOWLEDGEMENT

I am grateful to Late Dr. Suresh Masram Professor, Department of zoology, RTM Nagpur university, Nagpur for the valuable and inspiring guidance throughout the course of the work. His encouragement and guidance have provided a good support to me.

#### REFERENCES

- [1] Lawrence N.M. Study on the use of biopesticides against cotton insect pests under field conditions and their cost benefits. Ph.D dissertation, University of KwaZulu-Natal Pietermaritzburg Republic of South Africa. 2022.
- [2] Abdollahdokht D., Gao Y., Faramarz S., Poustforoosh A., Abbasi M., Asadikaram G. and Nematollahi M.H. Conventional agrochemicals towards nano-biopesticides: an overview on recent advances. Chemical and Biological Technology in Agriculture, 9:13.2022.
- [3] Pal G. K., Kumar B., Shahi S. K. Antifungal activity of some common weed extracts against seed borne phytopathogenic fungi *Alternaria* spp. International Journal of Universal Pharmacy and Life Sciences 3 (2): 2249-6793. 2013.
- [4] Pestovsky Y.S. and Antonio A.M. The Use of Nanoparticles and nanoformulations in agriculture. Nanoscience and Nanotechnology, 17(12): 8699–8730. 2017.
- [5] Misra N.A., Misra M. and Singh R. Nanotechnology in Agriculture and Food Industry. International Journal of Pure and Applied Sciences and Technology, 16(2): 1-9. 2013.
- [6] Jampilek J. and Kralova K. Nanobiopesticides

- in agriculture: State of the art and future opportunities. Nano-biopesticides Today and Future Perspectives, 397-447. 2019.
- [7] Pentak D., Kozik V., Bak A., Dybał P., Sochani K. A. and Jampilek J. Methotrexate and cytarabine loaded nanocarriers for multidrug cancer therapy. Spectroscopic Study Molecules, 21: 1689. 2016.
- [8] Korbekandi H., Irvani S. and Abbsi S. Production of nanoparticles using organisms. Critical reviews in Biotechnology, 29(4): 279-306. 2009.
- [9] Raliya R., Saharan V., Dimkpa C. and Biswas P. Nanofertilizer for precision and sustainable agriculture: Current state and future perspectives. Journal of Agricultural and Food Chemistry, 66: 6487–6503. 2017.
- [10] Letchumanan, D., Sok, S.P.M., Ibrahim, S., Nagoor, N.H. and Arshad, N.M. Plant-Based Biosynthesis of Copper/Copper Oxide Nanoparticles: An Update on Their Applications in Biomedicine, Mechanisms, and Toxicity. Biomolecules, 11, 564. 2021.
- [11] Chakraborty N., Banerjee J., Chakraborty P., Banerjee A., Chanda S., Ray K., Acharya K. and Sarkar J. Green synthesis of copper/copper oxide nanoparticles and their applications: a review, Green Chemistry Letters and Reviews, 15:1, 187-215. 2022.
- [12] Manna S., Roy S., Dolai A., Ravula A.R., Perumal V. and Das A. Current and future prospects of “all-organic” nanoinsecticides for agricultural insect pest management. Frontiers Nanotechnology, 4:1082128. 2023.
- [13] Khan I., Saeed K. and Khan I. Nanoparticles: Properties, applications and toxicities. Arabian Journal of Chemistry, 1878-5352. 2017.
- [14] Labaran, A.N., Zango, Z.U., Tailor, G. *et al.* Biosynthesis of copper nanoparticles using *Alstonia scholaris* leaves and its antimicrobial studies. 14, 5589. 2024.
- [15] Nagar, N., & Devra, V. Green synthesis and characterization of copper nanoparticles using *Azadirachta indica* leaves. Materials Chemistry and Physics, 213, 44–51. 2018.
- [16] Vora, S., Valera, H., Tavadia, M., Vakharia, H. and Singh, S. Green synthesis, characterization, and antimicrobial properties of Copper Nanoparticles from *Nerium Oleander* leaf aqueous extract. European Journal of Pharmaceutical Sciences. 4(12). 692-699. 2017.
- [17] Mohamed, E. A. Green synthesis of copper & copper oxide nanoparticles using the extract of seedless dates. Heliyon, 6(1), e03123. 2020.
- [18] Ghosh, M. K., Sahu, S., Gupta, I., and Ghorai, T. K. Green synthesis of copper nanoparticles from an extract of *Jatropha curcas* leaves: characterization, optical properties, CT-DNA binding and photocatalytic activity. RSC Advances, 10(37), 22027–22035. 2020.
- [19] Bhuvaneshwari, V., Vaidehi, D., Bharathi, D., and Sheetal, B. P. Antibacterial and photocatalytic activity of copper oxide nanoparticles synthesized using *Solanum lycopersicum* leaf extract. Materials Research Express, 5(8), 1-27. 2018.
- [20] Sivaraj, R., Rahman, P. K. S. M., Rajiv, P., Salam, H. A., & Venckatesh, R. Biogenic copper oxide nanoparticles synthesis using *Tabernaemontana divaricate* leaf extract and its antibacterial activity against urinary tract pathogen. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 133, 178–181. 2014.
- [21] Saif, S., Tahir, A., Asim, T., & Chen, Y. Plant Mediated Green Synthesis of CuO Nanoparticles: Comparison of Toxicity of Engineered and Plant Mediated CuO Nanoparticles towards *Daphnia magna*. Nanomaterials, 6(11), 205. 2016.
- [22] Akhter, G., Khan, A., Ali, S. G., Khan, T. A., Siddiqi, K. S., & Khan, H. M. Antibacterial and nematocidal properties of biosynthesized Cu nanoparticles using extract of holoparasitic plant. SN Applied Sciences, 2(7). 2020.
- [23] Kulkarni, V. D. and Kulkarni, P. S. Green Synthesis of Copper Nanoparticles Using *Ocimum Sanctum* Leaf Extract. International Journal of Chemical Studies, 1(3). 2013.
- [24] Toala, S. R., Gutierrez-Miceli, F., Valdez-Salas, B., Beltran-Partida, E., Gonzalez-Mendoza, D., Tzintzun-Camacho, O., Grimaldo-Juarez, O. and Basilio-Cortes, A. Biosynthesis of Copper Nanoparticles from *Acacia cornigera* and *Annona purpurea* and Their Insecticidal Effect against *Tribolium castaneum*. Reactions 2024, 5, 274–284.
- [25] Govindasamy, S., Marimuthu, T. and Vaiyazhipalayam, M.S. Optical, catalytic and antibacterial properties of phytofabricated CuO nanoparticles using *Tecoma castanifolia* leaf extract. Optik - International Journal for Light and Electron Optics, 127(19), 7822–7828. 2016.

- [26] Sankar, R., Manikandan, P., Malarvizhi, V., Fathima, T., Shivashangari, K. S., and Ravikumar, V. Green synthesis of colloidal copper oxide nanoparticles using *Carica papaya* and its application in photocatalytic dye degradation. *Spectrochimica Acta - Part A: Molecular and Biomolecular Spectroscopy*, 121, 746–750. 2014.
- [27] Dey, A., Manna, S., Chattopadhyay, S., Mondal, D., Chattopadhyay, D., Raj, A., Das, S., Bag, B. G., & Roy, S. *Azadirachta indica* leaves mediated green synthesized copper oxide nanoparticles induce apoptosis through activation of TNF- $\alpha$  and caspases signaling pathway against cancer cells. *Journal of Saudi Chemical Society*, 23(2), 222–238. 2019.
- [28] Bitire, S. O., and Jen, T. C. The role of a novel green synthesized nanoparticles added parsley biodiesel blend on the performance-emission characteristics of a diesel engine. *South African Journal of Chemical Engineering*, 41, 161–175. 2022.
- [29] Jadhav, M. S., Kulkarni, S., Raikar, P., Barretto, D. A., Vootla, S. K. and Raikar, U. S. Green biosynthesis of CuO & Ag-CuO nanoparticles from *Malus domestica* leaf extract and evaluation of antibacterial, antioxidant and DNA cleavage activities. *New Journal of Chemistry*, 42(1), 204–213. 2017.
- [30] Manogar P., Venkatesan, R., Deepa, S., Sana S., Arumugam S., Karami A., Vetcher A. and Kim S. Green synthesis, characterization, antibacterial, and antifungal activity of copper oxide nanoparticles derived from *Morinda citrifolia* leaf extract. *Scientific Reports*, 13(1). 2023.
- [31] Tolaymat TM, El Badawy AM, Genaidy A et. al. An evidence based environmental perspective of manufactured silver nanoparticle in syntheses and applications: a systematic review and critical appraisal of peer-reviewed scientific papers. *Sci Total Environ* 408:999–1006. 2010.
- [32] Ashmouny, R. S., Rady, M. H., Merdan, B. A., El-Sheikh, T. A. A., Hassan, R. E., & Gohary, E. G. E. Larvicidal and pathological effects of green synthesized silver nanoparticles from *Artemisia herba-alba* against *Spodoptera littoralis* through feeding and contact application. *Egyptian Journal of Basic and Applied Sciences*, 9(1), 239–253. 2022.
- [33] Rouhani M., Samih M.A. and Kalantari S. Insecticidal effect of silica and silver nanoparticles on the cowpea seedbeetle, *Callosobruchus maculatus* F. (Coleoptera: Bruchidae) *Journal of Entomological Research* 4(4): 297-305. 2012.
- [34] Periakaruppan, R., Manju Praveena, S., Priya, C., Ranjitha, P., Gokul Raj, S., and Danaraj, J. Biosynthesis of Silica Nanoparticles Using the Leaf Extract of *Punica granatum* and Assessment of Its Antibacterial Activities Against Human Pathogens. *Applied Biochemistry and Biotechnology*, 194(11), 5594–5605. 2022.
- [35] Mohd, N. K., Wee, N. N. A. N., and Azmi, A. A. Green synthesis of silica nanoparticles using sugarcane bagasse. *AIP Conference Proceedings*, 1885. 2017.
- [36] Rahimzadeh, C. Y., Barzinjy, A. A., Mohammed, A. S., and Hamad, S. M. Green synthesis of SiO<sub>2</sub> nanoparticles from *Rhus coriaria* L. extract: Comparison with chemically synthesized SiO<sub>2</sub> nanoparticles. *PLoS ONE*, 17 (8): e0268184. 2022.
- [37] Fouda A., Eid A.M., Abdel-Rahman M.A., Beley E.F., Awad M.A., Hassan S. D., Faifi Z.E. and Hamza M.F. Enhanced Antimicrobial, Cytotoxicity, Larvicidal, and Repellence Activities of Brown Algae, *Cystoseira crinita*-Mediated Green Synthesis of Magnesium Oxide Nanoparticles. *Frontiers in Bioengineering Biotechnology*. 10:849921. 2022.
- [38] Younis, I. Y., El-Hawary, S. S., Eldahshan, O. A., Abdel-Aziz, M. M., & Ali, Z. Y. Green synthesis of magnesium nanoparticles mediated from *Rosa floribunda charisma* extract and its antioxidant, antiaging and antibiofilm activities. *Scientific Reports*, 11(1). 2021.
- [39] Jeevanandam, J., Chan, Y. S., and Danquah, M. K. Biosynthesis and characterization of MgO nanoparticles from plant extracts via induced molecular nucleation. *New Journal of Chemistry*, 41(7), 2800–2814. 2017.
- [40] Sharma, S. K., Khan, A. U., Khan, M., Gupta, M., Gehlot, A., Park, S., and Alam, M. Biosynthesis of MgO nanoparticles using *Annona squamosa* seeds and its catalytic activity and antibacterial screening. *Micro and Nano Letters*, 15(1), 30–34. 2020.
- [41] Nguyen, D. T. C., Dang, H. H., Vo, D. V. N., Bach, L. G., Nguyen, T. D., and Tran, T. V. Biogenic synthesis of MgO nanoparticles from

- different extracts (flower, bark, leaf) of *Tecoma stans* (L.) and their utilization in selected organic dyes treatment. *Journal of Hazardous Materials*, 404. 2020.
- [42] Shahid, S., Ejaz, A., Javed, M., Mansoor, S., Iqbal, S., Elkheed, E. B., Alzhrani, R. M., Alsaab, H. O., Awwad, N. S., Ibrahim, H. A., Fatima, U., Zaman, S., & Nazim Sarwar, M. The Anti-Inflammatory and Free Radical Scavenging Activities of Bio-Inspired Nano Magnesium Oxide. *Frontiers in Materials*, 9:875163. 2022.
- [43] Hussain, S., Ali Muazzam, M., Ahmed, M., Ahmad, M., Mustafa, Z., Murtaza, S., Ali, J., Ibrar, M., Shahid, M., and Imran, M. Green synthesis of nickel oxide nanoparticles using *Acacia nilotica* leaf extracts and investigation of their electrochemical and biological properties. *Journal of Taibah University for Science*, 17(1). 2023.
- [44] Pandian, C. J., Palanivel, R., and Dhananasekaran, S. Green synthesis of nickel nanoparticles using *Ocimum sanctum* and their application in dye and pollutant adsorption. *Chinese Journal of Chemical Engineering*, 23(8), 1307–1315. 2015.
- [45] Ahmad, W., Bhatt, S. C., and Kaur, N. Plant extract mediated approach towards the synthesis of NiO nanoparticles: Evaluation of its antibacterial, antioxidant and photocatalytic activity. *Vietnam Journal of Chemistry*, 61(4), 445–454. 2023.
- [46] Rahman, M. A., Parvin, A., Khan, M. S. H., Lingaraju, K., Prasad, R., Das, S., Hussain, B., War R.A. and Bhattacharyya, A. Efficacy of the green synthesized nickel-oxide nanoparticles against pulse beetle, *Callosobruchus maculatus* (F.) in black gram (*Vigna mungo* L.). *International Journal of Pest Management*, 1–9. 2020.
- [47] Ashram S., Ali A.M., Osman S.E., Huang S., Shouman A.M., Kheirallah D.A. Biochemical and histological alterations induced by nickel oxide nanoparticles in the ground beetle *Blaspolychresta* (Forskl, 1775) (Coleoptera: Tenebrionidae). *Public Library of Science One*, 16(9): e0255623. 2021.
- [48] Jeyaraman, R., Kadarkaraihangam, J., Arumugam, M., Govindasamy, R., Rahuman, A. Thirunavukkarasu, S., Arivarasan, V., Chidambaram, J. and Sampath M. Copper nanoparticles synthesized by polyol process used to control *hematophagous parasites*. *Parasitology Research*, 109(5), 1403–1415. 2011.
- [49] Renganathan, S., Saranyaadevi, K., Subha, V., Ramaswami, S. and Ernest R. Green synthesis and characterization of silver nanoparticle using leaf extract of *Capparis zeylanica*. *Asian Journal of Pharmaceutical and Clinical Research*. 7(2): 44-48. 2014.
- [50] Maji, A., Beg, M., Das, S., Aktara, M. N., Nayim, S., Patra, A., Islam, M. M., & Hossain, M. Study on the antibacterial activity and interaction with human serum albumin of *Tagetes erecta* inspired biogenic silver nanoparticles. *Process Biochemistry*, 97, 191–200. 2020.
- [51] Helaly A.A., Benda., Wahab A.S., Sheikh M.A. and Elnagar S. The silica-nano particles treatment of squash foliage and survival and development of *Spodoptera littoralis* larvae. *Journal of Entomology and Zoology Studies*, 4(1): 175-180. 2016.
- [52] Ayoub H.A., Khairy M, Rashwan F.A. and Hafez H.A. Synthesis and characterization of silica nanostructures for cotton leaf worm control. *Journal of Nanostructure in Chemistry* 7:91–100. 2017.
- [53] Hashem M.Y., Sabbour M.M., Ahmed S.S., Elrhman A., Montaser A.S. and Mohamed K.M. Efficacy of silica nanoparticles on cotton leafworm larvae, *Spodoptera littoralis* (Lepidoptera: Noctuidae). *Plant Archives*, 19(2), 2019: 2601-2607. 2019.
- [54] Hamdy E., Al-Askar A. A., El-Gendi H., Khamis W. M., Behiry S. I., Valentini F. and Abdelkhalek, A. Zinc oxide nanoparticles biosynthesized by *Eriobotrya japonica* leaf extract: Characterization, insecticidal and antibacterial properties. *Plants*, 12(15): 2826. 2023.
- [55] Saleh, HA, Soheir F. Abd El-Rahman , A. R. El-Gably, Sh. S. Yacoub and A. M. Khorchid. Biological and Histological Effects of Certain Insecticides on *Spodoptera littoralis* (Bosid). *Journal of Plant Protection and Pathology*. 12 (2): 111 – 115. 2021