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Review

The Multifaceted Perspective on the Role of Green Synthesis of Nanoparticles in Promoting a Sustainable Green Economy

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Abstract: The current economic development paradigm, which is based on steadily rising resource consumption and pollution emissions, is no longer viable in a world with limited resources and ecological capacity. The "green economy" idea has presented this context with a chance to alter how society handles the interplay between the environmental and economic spheres. The related concept of "green nanotechnology" aims to use nano-innovations within the fields of materials science and engineering to generate products and processes that are economically and ecologically sustainable, enabling society to establish and preserve a green economy. Many different economic sectors are anticipated to be impacted by these applications, including those related to corrosion inhibitor nano fertilizers, nano remediation, biodegradation, heavy metal detection, biofuel, insecticides & pesticides, and catalytic CO_2 reduction. These innovations might make it possible to use non-traditional water sources safely and to create construction materials that are enabled by nanotechnology, improving living and ecological conditions. Therefore, our aim is to highlight how nanotechnology is being used in the green economy and to present promises for nano applications in this domain. Additionally, we want to critically examine the practical difficulties these applications raise, especially in consideration of any possible implications for the health and safety of those employed within this innovative sector.   In the end, it emphasizes how critical it is to attain a really sustainable advancement in nanotechnology.

Keywords: biofuel; insecticides; pesticides; catalytic reduction of CO_2; green economy; sustainability; biodegradation; nanoparticles; corrosion inhibitor; nanofertilizer; heavy metal detection

1. Introduction

Many factors have contributed to the widespread acceptance of the "green economy" concept in policy discussions. These include the ongoing global economic crisis, the projected increase in global energy demand of more than one-third between 2010 and 2035, price hikes for commodities, and the urgent need to address global issues about energy, the environment, and health. The term "green economy," which mostly relates to the ideas of sustainable development, was first used by a group of well-known environmental economists in a revolutionary 1989 assessment for the federal government of the United Kingdom [1–3]. The most widely recognized and reliable definition of a "green economy" comes from the United Nations Environment Programme, which states that one is "a green economy if it leads to enhanced human well-being and social equity while substantially decreasing environmental risks and environmental shortages." It is socially inclusive, low-carbon, and resource-efficient [4].

A collection of concepts, objectives, and practices collectively referred to as the "green economy" include: (i) advocating for justice and equity for all generations; (ii) upholding sustainable development principles; (iii) applying caution about the environment and social effect; (iv) appreciating natural and social capital through techniques such as whole-life expenses, internalizing

external costs, and enhancing governance; (v) utilizing resources wisely and effectively; and (vi) aligning with previously present macroeconomic objectives by abolishing poverty, fostering green jobs, and enhancing competitiveness as well as development in significant industries[3–7].

Nanoparticles play a key role in the transition of a green economy to sustainable and environmentally friendly technologies due to their unique properties. At the nanoscale, these materials present chances to create economically viable and energy-efficient solutions that support the goals of the green economy [8].

The application of nanoparticles in the green economy has the potential to revolutionize various industries and promote sustainability. However, it's crucial to acknowledge that while nanomaterials can offer significant benefits for sustainable processes and products, there are associated challenges. These include moral and social issues, ambiguities around commercial acceptability, environmental as well as safety concerns, and competition with traditional technologies. To ensure the success of nanoparticle applications in the green economy, careful consideration of these factors is essential to strike a balance between innovation and responsible implementation [9].

This study examines the opportunities and real-world challenges that nano-applications offer for addressing the principles of a green economy. There are examples given of how nano-applications could help with social and environmental issues. Green synthesis produces highly efficient nanoparticles without affecting the environment. The goal of this review article is to promote the use of regional botanical items for the synthesis of nanoparticles and their application for the control of environmental issues that harm both human health and the environment. Such a problem is faced worldwide, either in developed countries, developing countries, or underdeveloped countries. This review supports the pathway to prepare nanoparticles and use them for mitigation in eco-friendly means, which is also a visionary action for sustainable development. This review is also concerned with the green synthesis of nanoparticle and their mitigation approach toward environmental problems, etc. Moreover, the study also focuses on the unique approach of green synthesis of nanoparticles, which are highly efficient, responsive to external stimuli, and cheap. The transformative potential of green nanotechnology across various sectors such as biofuel, CO_2 reduction, detection of heavy metals, and many more is demonstrated graphically in Figure 1.
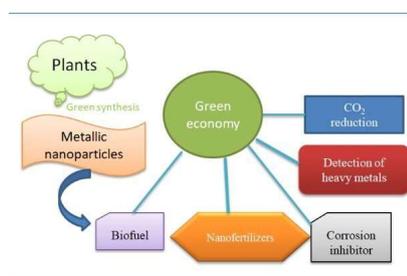

Figure 1. Exploring the transformative potential of green nanotechnology across various sectors.

2. Green Synthesis

The environmentally friendly synthesis of nanoparticles is essential for the development of a green economy because it provides viable substitutes for conventional synthesis techniques. This environmentally beneficial method reduces the need for dangerous chemicals and energy-intensive procedures by utilizing biological sources, such as bacteria and plants. Green synthesis is the process of recycling biological and agricultural waste to minimize environmental effects while fostering resource efficiency and the circular economy. The resultant nanoparticles frequently show improved biocompatibility, which qualifies them for use in industry, agriculture, and medicine. Furthermore, the method supports international efforts to promote ecologically friendly practices and generates economic opportunities through the valorization of biomass. All things considered, the green synthesis of nanoparticles addresses environmental issues, encourages innovation and supports responsible resource management, all of which lead to a more robust and sustainable economy [10,11]

A broad area of study encompassing multiple nanotechnology applications. There is now a trend to employ NPs for environmental purposes. Metallic nanoparticles are one of the many kinds of nanoparticles (NPs) employed in environmental applications. Plant-assisted synthesis of NPs is more affordable, ecologically benign, and commercially feasible than chemical and physical procedures [13]. Most often, in green synthesis, plant components are used as reducing and capping agents. Leaf, bark, fruit, and flower extracts have been used to make metallic nanoparticles (NPs) of a variety of sizes and shapes [14]. Biosurfactants generated from microbes, plants, and other biological resources have also been used in the manufacturing of metallic nanoparticles. Bio-fabricated metallic nanoparticles can be used to detect and eliminate metal dyes, antibiotics and metal ions [15]. Particles made via green synthesis are not the same as particles generated via physicochemical methods. Metal or metal oxide nanoparticles were created by employing the bottom-up method. In green synthesis, a natural extract such as fruit leaves, crops, or plants was combined with a costly chemical reduction agent. There is a huge potential for the creation of NPs in biological entities. The application of nanoparticles derived from plants is given in Table 1.

Table 1. Nanoparticles from Plants and their Applications.

Plant	Nanoparticles	Applications	Reference
Ficuscarica	Fe_3O_4	Antioxidant	[16]
Azadirachtaindica	CuO	Anticancer	[16]
Peltophorumpterocarpum	Fe_3O_4	Degradation of Rhodomine	[17]
Terminalia chebula	Fe_3O_4	Degradation of MB	[17]
Punicagranatum	ZnO	Antibacterial	[18]
Lactucaserriols	NiO	Dye Degradation	[19]
Vitisrotundifolia	CoO	Acid blue dye degradation	[20]
Ziziphus spina-christi	ZnO-SeO	Antimicrobial/ antioxidant activity	[21]
Seriphidiumoliverianum	CuO	Photocatalytic dye degradation from water	[22]
Punicagranatum	Ag_2O	antibiotic removal from wastewater	[23]
Jacaranda mimosaefolia	Cu	Corrosion inhibition	[24]
Scallion's peel	ZnO	Nano fertilizer	[25]
FicusBenjamina	TiO_2	Heavy metal detection	[26]
watermelon	CaO	The catalyst for biofuel production	[27]
Cola nitida	FeO	Absorption of MB/MO dye from wastewater	[28]

3. Applications

The current economic model is no longer viable in a society with finite resources and ecological capability since it depends on increasing pollution and resource consumption. The idea of the "green economy" presents an opportunity to redefine the environment-economic interface. "Green nanotechnology" affects industries including biofuel, nanofertilizers, nanoremediation, and more by employing materials science's nanotechnologies to create economically and ecologically sound goods. Our goals are to address issues, particularly those related to worker health and safety, to emphasize the role that nanotechnology plays in promoting a green economy, and to underscore the necessity of sustainable advancements in nanotechnology. Moreover, the explanation is illustrated below:

4. Corrosion Inhibitor

Due to its ability to increase the sustainability and efficiency of corrosion protection techniques, nanoparticles' involvement in corrosion inhibition significantly advances the green economy. As corrosion inhibitors, nanoparticles provide metallic surfaces with durable protection that lowers maintenance costs and increases infrastructure longevity. Environmentally friendly and economical methods are frequently used in the application of these nanomaterials, which reduces the ecological impact of corrosion prevention and conserves resources. Adopting corrosion inhibition technologies based on nanoparticles helps companies become cleaner and more sustainable, which is in line with international initiatives to lessen the environmental impact of different sectors. This shift creates a market for environmentally friendly corrosion prevention products in the developing green economy while also ensuring the longevity of vital infrastructure and promoting innovation and job creation [29-31].

A range of natural deep eutectic solvents was synthesized using various polyphenols sourced from plants, and choline chloride was employed as a corrosion inhibitor for mild steel [26]. By depositing surfactant $C_{16}H_{33}N+(CH_3)3[CeCl_3Br]−(CTACe)$-modified silica nanoparticles, a metallic material was endowed with a good resistance to corrosion [27]. Fifteen distinct kinds of amino acids were present in the hydrolysate, and their adsorption on the surface effectively prevented the steel from corroding in the acidic media. [28]. Corrosion can be managed and averted through diverse methods such as combining manufacturing fluids, enhancing material quality, implementing chemical barriers, and various other approaches [32,33]. Therefore, their effectiveness in preventing and managing surface deterioration of metals caused by various corrosive substances is regarded as the most significant corrosion inhibitors [34,35]. Table 2 lists the nanoparticles that were isolated from the plant with the corresponding efficacy.

Table 2. Nanoparticle for Green Corrosion Inhibitor.

Nanoparticle	Plant	Effect	Efficiency	reference
Glycogen NP	Biogenic sources	Controlled the corrosion of zinc in sulfamic acid (NH_2SO_3H)	92% for 0.02 gL^{-1}	[23]
CuO	*Moringa oleifera* leaf extract	Improved overall anticorrosive activity	56%	[59, 36]
Manganese oxide	Rose petal (RP) and lotus petal (LP)	Overall anticorrosion behavior of mild steel increased	72.63%	[23]
Ag	*Citrus reticulata* peels extract	Inhibited steel corrosion from HCl	93.9% at 303K and 90.3% at 333K	[37]
Ag	palm oil leaf extracts	A protective film formed which protected the	94.1%	[38]

		steel from acid attack		
Ag nanocomposite	Red onion peels	A surface protection layer formed against corrosion	86%	[39]
Cellulose nanocrystal	Organic product	Protected AISI360-steel from corrosion in petroleum manufacturing.	85.3% at 300 mg L^{-1}	[40]
CuO/melamine /cellulose nanocrystals nanocomposite	Organic product	Protected AISI360-steel from corrosion in petroleum manufacturing.	96.8% at 300 mg L^{-1}	[41]
NiO/melamine/ cellulose nanocrystals nanocomposite	Organic product	Protected AISI360 steel from corrosion in petroleum manufacturing.	98.3% at 300 mg L^{-1}	[42]

5. Nano fertilizer

Through the optimization of agricultural output and resource utilization, nano fertilizers are essential to the advancement of the green economy. By precisely delivering nutrients, nanofertilizers increase crop yields and foster economic efficiency in the agriculture industry. Farmers save money because of the reduced need for fertilizer due to the regulated release of nutrients. Moreover, nano fertilizers help to ensure the sustainability of agricultural operations and their long-term economic viability by reducing environmental consequences including pollution and nutrient runoff. In addition to providing financial benefits to farmers, the technology's ability to enhance soil health and nutrient use efficiency positions agriculture as a more resilient and environmentally conscious component of the broader green economy. The broad use of nano fertilizers holds promise for a more environmentally and economically sustainable agricultural future as they continue to provide benefits through higher yields, resource conservation, and less environmental externalities [43-45].

The use of zinc oxide nanoparticles as a foliar fertilizer has been shown in several studies to enhance the agro-morphological characteristics, photosynthesis, and yields of wheat plants [46] and common bean plants. Tomato plants' traits and yield are enhanced by carbon nanoparticles [47]. Zinc oxide nanoparticles are a more effective way to support wheat growth and germination than zinc sulphur dioxide. Additionally, at larger dosages, they demonstrated in the literature that zinc sulphur dioxide posed a greater risk than ZnO-NPs [48]. The common bean that is harvested from the ZnO-NP-treated plant affects the lipid parameters and the liver and renal functions of the rats that consume it [13]. Many plants, like squash, require the three nutrients iron, manganese, and zinc to flourish [49,50]. Furthermore, as observed by Kaur et al., the application of Mn nano oxide greatly decreased the yield of fruit squash (kg/plant and tons/hectare), particularly when coupled with the application of Fe nano oxide. It was also mentioned that the fruits of squash plants sprayed with Fe oxide nanoparticles had higher concentrations of energy, proteins, lipids, and organic matter [13].

Moreover, NFs may raise plants' defence mechanisms, lengthen stress resistance, and improve nutrient absorption and output by maintaining the accessibility of nutrients in the rhizosphere. Due

to their better suitability for promoting plant development, they can potentially replace synthetic fertilizers and provide a new route for sustainable and healthy agriculture [51]. They reduce external pressures and improve tolerance to unfavourable environmental conditions for plants. Recent nano-technological developments have been filling the gaps between agriculture and technology and have craved a sustainable plan for solving the global food crisis [52]. In light of this, nanoparticles are quickly becoming a cutting-edge agro-technology for agro-improvement. Surprisingly, they give crop plants the ability to resist stress [53]. Additional nano-fertilizers have been studied with respective plants and are given in Table 3.

Table 3. Nanoparticles used as Nano-fertilizers.

Nanoparticle	Plant affected	Effect	Reference
Hydroxylapatite $(Ca_5(PO_4)_3OH)$	Soybean (*Glycine max*)	Increase of 33% growth rate and 20% seed yield	[54]
AgNPs	red ginseng shoot	Ginsenoside content increased	[55]
TiO$_2$	aged spinach seeds	Increased germination rate due to increase in nitrogen assimilation	[56]
Iron oxide	Soybean	48% increase in grain yield	[57]
Ag	*Fusarium solani*	Reduced fungal infection	[58]
C nanoparticle	*Phaseolus vulgaris L.*	Improved the quality and constituents of leaves and seeds.	[59]
K^+, Fe, tryptophan, urea, amino acids	tomato, fenugreek	Increased germination percentage of tomato from 14% to 97% and fenugreek from 25% to 93.14%.	[60]
Nano-NPK	*Capsicum annuum* leaves	Caused better quality of fruit and increased the yield too.	[61]

6. Heavy metal detection

By solving environmental issues and fostering economic sustainability, the use of nanoparticles in heavy metal detection is crucial to the growth of the green economy. When used with state-of-the-art sensing technologies, nanoparticles improve the accuracy and efficacy of heavy metal detection techniques, allowing for the early detection of pollution in soil, water, and air. This reduces the financial burden of environmental cleanup and medical costs while also protecting human health and ecosystems [62]. Industries are adopting detecting systems based on nanoparticles in compliance with strict environmental rules, which lowers the possibility of legal repercussions and increases corporate accountability. Businesses that invest in and use these technologies not only help to create a cleaner and healthier environment but also boost economic growth by creating and distributing novel solutions that support a green economy that is more robust and sustainable [63-64].

The primary heavy metals that are environmentally hazardous in recent research are Pb^{2+}, Cr^{3+}, Hg^{2+}, As^{3+}, and Cu^{2+}. As a result, several attempts have been undertaken to measure and detect heavy metals using analytical techniques [65]. However, current technology is still needed for the sensitive and user-friendly detection of heavy metals. In reaction to this, nanotechnology was created. These nanotechnologies were demonstrated to be extremely sensitive, selective, and fast-acting, which improved the efficacy of analytical equipment [66]. For several reasons, including their low detection limit, high linear range, and ease of system integration, nano-based sensors are an effective tool for on-the-spot identification or on-field recognition. The benefits of using ways based on nanotechnology gave them a new idea for combining these technologies into portable devices that can be used anywhere and at any time, as Figure 2 [67] illustrates. Table 4 also contains a tabulation of the nanoparticles that were employed to detect heavy metals.
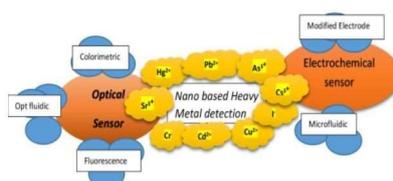

Figure 2. Nanoparticle intervention for heavy metal detection [67].

Table 4. Nanoparticle for detection of heavy metal detection.

Nanoparticles	Heavy metal detected	Limit of detection	Reference
Multiwalled carbon nanotube	Zn (II)	$0.3\ \mu gL^{-1}$	[68]
Multiwalled carbon nanotube	Pb (II)	$0.07\ \mu gL^{-1}$	[68]
Multiwalled carbon nanotube	Cd (II)	$0.1\ \mu gL^{-1}$	[68]
CNT/ Pt	As (III)	-	[69]
Au-decorated Te hybrids	As (III)	0.0026 ppb	[70]
AuNP	Hg (II)	-	[71]
AuNP	As	$0.01\ \mu M$	[72]
Graphene	Cd (II)	$10^{-7}\ M$	[73]
Graphene oxide	Cd (II)	$0.1\text{-}1.5\ \mu M$	[74]
Graphene oxide	Hg (II)	$2.5 \times 10^{-8}\ M$	[75]
AuNP	Cr	$0.01\ \mu M$	[75]
Carbon nanofibers	Bi (III)	$16.8\ \mu gL^{-1}$	[76]
Carbon nanofibers	In (III)	$3\ \mu gL^{-1}$	[76]

7. Biofuel

One of the keystones for advancing the green economy is the use of nanoparticles in the manufacturing of biofuel. When used as additives or catalysts, nanoparticles improve the productivity of biofuel synthesis processes, leading to higher yields and lower production costs. They play a key role in increasing the production of sustainable fuels because of their capacity to enhance reaction conditions and the overall effectiveness of biofuel production technologies. The application of nanoparticles makes it easier to create economical and ecologically beneficial processes for producing biofuels, which draws capital and promotes economic expansion in the renewable energy industry. A more effective and financially feasible route to sustainable energy is made possible by industries' growing adoption of nanoparticle technology for the manufacturing of biofuels. This

boosts the green economy overall by fostering innovation in the renewable energy industry and generating jobs [77-79].

A range of products have been produced as replacements for previously utilized fossil fuels through several green synthesis projects. Utilizing green copper oxide nanoparticles for enhanced transesterification of citrus medica-generated biodiesel in the core composite design. This green biodiesel that was manufactured adhered to international standards for properties like methyl ester. The biodiesel generated by the green $CaTiO_3$ catalyzed transesterification reaction reached 97.5%, and the catalyst may be reused several times, demonstrating 80% efficacy on the fifth usage. The characteristics of the biodiesel generated by this procedure demonstrate that it falls within the range of ASTM criteria. Green ZnO nanoparticles produced from banana corm extract showed significant performance in the production of biodiesel from waste fish lipids, with an ideal yield of 2.5% and over 90% transesterification efficiency [80]. The use of nanoparticles as catalysts for the production of biofuels are given in Table 5.

Table 5. Nanoparticles used as the catalyst for biofuel.

Nanoparticles	Effect	Reference
Carbon nanotubes	Used in biosensors and microbial fuel cell fabrication as well as a catalyst in biofuel production also raises the overall concentration of enzymes in biofuel generation as well as helps in enzyme mobilization	[81,82]
Aniline incorporated with $Fe_3O_4-NH_2$ and reduced graphene oxide nanocomposite	Enhanced the process of bio-electrocatalysis of glucose oxidase	[83]
magnetic nano ferrites doped with calcium	Raises biodiesel production yield	[84]
MnO_2 with sugarcane leaf	Increased bioethanol synthesis	[85]
Nano zero-valent iron (nZVI) and Fe_2O_3	Improves the production of biogas like methane	[86]
CeO_2	Improved the production of biogas	[87]
Pt and silica	Raises methane production yield	[88]
Ni and silica	Raises methane production yield	[88]
Co and silica	Raises methane production yield	[88]
Fe and silica	Raises methane production yield	[88]

8. Catalytic Reduction of CO_2

When it comes to catalytic CO_2 reduction, nanoparticles are revolutionary and greatly advance the green economy. These small catalysts, which are frequently made of sustainable materials, improve the effectiveness of CO_2 conversion processes and open up new economic opportunities by producing useful chemicals and fuels. Their distinctive characteristics and large surface area improve catalytic efficacy, maximizing reaction rates and lowering energy inputs. The commercial feasibility of CO_2 reduction technologies can be enhanced by the application of nanoparticles, which can result in scalable and affordable catalytic systems. A new frontier of economic prospects arises as companies incorporate these catalysts based on nanomaterials more and more. Investment in sustainable

technology, innovation, and job creation propel the economy toward being greener and wealthier [89-91].

The environmentally benign photocatalytic reduction of CO_2 to CH_3OH is achieved by the use of nanoporous CeO_2, while sunlight is employed to initiate exothermic combustion, ensure uniform heating, and create vacancies in CeO_2. The homogeneous distribution of heat energy made possible by the nanosize can raise CeO_2's reduction efficiency [92]. The triple-functional precursor NH_3BH_3, which has a narrow band that enhances light energy harvesting and electron transfers via the catalyst for surface adoption of CO_2 in reduction, was used to synthesise the B, N co-doped TiO_2 nanosheets [93]. Moreover, Table 6 tabulates the nanoparticle involved in CO_2 removal.

Table 6. Nanoparticles serve as a reduction of CO_2.

Nanoparticle	Treated along with	Period of experiment	Temperature	reference
CoNP-treated cocoa shell	Cocoa shell and 3-aminopropyltriethoxy silane		25 °C	[94]
magnetite nano capsules nanocomposite	polyaniline	90 minutes	28 °C	[94]
Porous silica nanoparticle	Polyethyleneimine	30 minutes	75 °C	[95]
La and Ce	Zeolite	-	0, 30, 60 °C	[95]
CaO	Eggshell waste	23 minutes	700-900 °C	[96]
MgO	Graphene oxide	-	60-120 °C	[96]

9. Insecticides & Pesticides

Due to their revolutionary effect on agricultural operations, nanoparticles in herbicides and insecticides represent a significant step toward the advancement of the green economy. Pesticides and insecticides using nanoparticle-based formulations have a more focused and regulated delivery system, which boosts effectiveness while reducing environmental impact. These nanoparticles help maintain soil health and biodiversity by lowering the need for overuse of chemicals in agricultural activities. The implementation of solutions based on nanoparticles improves resource efficiency and reduces the financial and ecological expenses linked to conventional pesticides. As a result, of industry investments in and use of these cutting-edge technologies, the objectives of a green economy are advanced and a more environmentally conscious and sustainable agricultural sector is fostered, as well as economic growth is stimulated through the development and commercialization of cutting-edge environmentally friendly pest control solutions [97-99].

The usage of nanoparticles as insecticides in agriculture has increased recently. It is also being used as an inexpensive sensing tool, which has to be studied for better farming practices and higher yields [92]. Low-cost resources may be obtained through green synthesis, which can also be utilized to produce biopesticides and medications for treating people and animals. Ulrichs et al. claim that NP has a large surface area that affects lepidopteran insects in less than a day, which is necessary for human use [93]. Table 7 presents a tabulation of the nanoparticles present in the activity along with their interaction pests.

Table 7. Nanoparticle serves as insecticides & pesticides.

Nanoparticle.	Activity	Pests affected	Reference

ZnO	Blocks the organism.	*Fusarium graminearum, Penicillium expansum, Alternaria alternate, F. oxysporum, Rhizopus stolonifer, Mucorplumbeus, Pseudomonas aeruginosa* and *Aspergillus flavus*	[92,93,97]
MO	Stops fungal conidiophores and conidia growth on vegetative parts of fungi	Conidia and conidiophores of fungi	[98]
C nanotubes	Raises the nutrients and elemental uptake by plants and is also involved in ameliorating the development of plants.		[99-100]
Ag	Is used to control agricultural pests and organisms.	*Helicoverpaarmigera, Ariadne merione, Pediculushumanus, Aedesstephensi, Aedes aegypti, Culex quinquefasciatus, Lipaphiserysimiwas, Plutellaxylostella, Helicoverpaarmigera*and *Sitophilus oryzae.*	[101- 107]
Cd	Causes larval death of 93.79% at 2400 ppm	*Spodopteralitura*	[108]
TiO$_2$	Causes larval death of 73.79% at 2400 ppm	*Spodopteralitura*	[108]
Pungam oil based AuNP	Causes high mortality of pests.	*Pericalliaricini* larvae	[109]
Cu	Causes toxicity against pests.	*Triboliumcastaneum, Spodopteralittoralis* larvae, *Aedes aegypti* larvae	[110-111]
nanostructured alumina (Al$_2$O$_3$)	Causes mortality when exposed to wheat pests.	*Sitophilus oryzae, and Rhizopertha Dominica*	[112]
Al	Kills the pest	*S. oryzae*	[113]
TiO$_2$	Destroys the pest	*S. oryzae*	[113]

Nanosilica	Enters inside the pest from the cuticle, thus, destroying the pest	Different pests	[114]
Nanosphere of silica	Helps bactericides to enter into plant cell sap	-	[115]
Bioactive silver	Lags the action of trypsin, hence, makes the pest harmless.	Different pests	[116]
AuNPs with protein	Improves catalytic inhibition	-	[117]

10. Conclusions

The substantial and adaptable influence of environmentally produced nanoparticles on a range of important fields, such as the development of insecticides and pesticides, the production of biofuel, the inhibition of corrosion, the use of nano fertilizers, the remediation of nano damaged materials, the facilitation of biodegradation, the detection of heavy metals, and the catalytic reduction of CO_2 to promote the green economy. Utilizing eco-friendly nanomaterials in novel ways highlights their revolutionary potential in advancing sustainability, as well as their ability to address urgent environmental and industrial issues. This research offers a promising path towards a more environmentally conscious and commercially successful future by utilizing the multifaceted properties of green-synthesized nanoparticles. It also strengthens the fundamental role that these nanoparticles will play in forming a more sustainable and greener world by providing comprehensive solutions for a range of industries.

Generally speaking, green nanotechnology needs to "become green" in terms of the attention it pays to worker safety and health in addition to offering green solutions. In this context, a thorough open debate between specialists is necessary to appropriately weigh the advantages of green nanotechnology against any possible costs to society, especially regarding public, occupational, and environmental health. This methodical planning procedure will work well advantages for society, the environment, health, and the economy reductions and increase the likelihood of additional funding being allocated to this exciting area of technology.

Future Perspectives:

1. Ongoing investigation into novel environmentally friendly nanoparticle production techniques.

2. Researching materials for biodegradable nanoparticles to lessen their influence on the environment.

3. The creation of intelligent nanofertilizers to minimize chemical usage and enable precision farming.

4. Using nanoremediation methods to remediate pollution in water and soil.

5. Improving the biodegradation processes based on nanoparticles to manage waste effectively.

6. Progress in heavy metal identification technology to enhance environmental surveillance.

7. Using catalysts made of nanoparticles to increase the generation of biofuels for sustainable energy.

8. Research how nanoparticles affect ecosystems and microbial communities.

9. Improving and extending the application of nanoparticles in herbicides and insecticides to manage pests.

10. Research on environmentally acceptable and sustainable substitutes for conventional chemical pesticides.

11. Using nanoparticles and catalytic reduction of CO_2 to fight climate change.

12. Examining the possibility of using nanoparticles for carbon collection and usage.

13. Developing rules and policies for the safe and responsible use of nanoparticles.

14. Public awareness initiatives to inform people about the advantages of green nanoparticles as well as any possible hazards.

15. Cooperation to hasten the adoption of green nanoparticles for a greener economy among businesses, academic institutions, and governments.

Ethical Approval

• The manuscript is not submitted to more than one journal for simultaneous consideration.

• The submitted work is original and should not have been published elsewhere in any form or language (partially or in full).

• A single study has not been split up.

• Results are presented, honestly, and without fabrication, falsification, or inappropriate data manipulation (including image-based manipulation). Authors adhere to discipline-specific rules for acquiring, selecting, and processing data.

• No data, text, or theories by others are presented as if they were the author's own ("plagiarism"). Proper acknowledgements of other works are given.

Abbreviations

ASTM	American Society for Testing and Materials
ZnO	Zinc Oxide
NPs	Nanoparticles
NFs	Nanofertilizers

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