CHAPTER 15

GREEN NANOTECHNOLOGY: THE NOVEL AND EMERGING STRATEGY FOR SUSTAINABLE DEVELOPMENT

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ABSTRACTS

A ground-breaking discovery of the 20th century is the ecologically sound Nanotechnology (NT). It can benefit many industries like for medical purposes – drugs (especially for cancer), surgeries, agriculture, cosmetics industry, fabrics, in many devices – computers, mobiles, waste material management, water treatment, and others. Green NT is a combined effort with green chemistry with engineering in modified ways and is investigating without distressing human health and the environment. Presently, the chapter emphasizes synthesizing green nanoparticles (NPs) and their prospective approaches at a multitude of organizations. The valuable part of this green revolution is the copious availability of its source, which can mitigate the effects of global warming and lessen both food security and productivity. Different plants, algae such as *Mikania* sp., diatoms, *Salvinia molesta*, etc., are used to extract the NPs and are used for variegated environmental practices both in and undeviating way or ambiguously. Moreover, those green NPs can also alter the metabolisms within plant bodies themselves, including oxidative stress, apoptosis-related changes, etc. Comprehensive investigations are going on globally for the nanomedicines, and usage of green NPs in drug delivery systems (DDS), and this field should acquire attention for the sake of more advanced civilization.

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15.1 INTRODUCTION

"Nano" is a Greek term that denotes a little dwarf or minute material with a magnitude of 10^{-9} m [104]. When dealing with the term "nano," two other phrases come up frequently: "nanoscience" and "nanotechnology," while NT is a subfield of nanoscience that specializes in developing devices, components, and systems with the smallest unit size possible (1 nm) [95, 138, 153]. NT has been used since the time of Democritus in the 5th century B.C. [101]. People believed that matter could be split down into numerous indestructible essential components, eventually referred to as atoms [152]. In the late 1800s, Dmitri Mendeleev and Lothar Meyer constructed periodic tables separately [35], widely regarded as the first method for arranging elements according to their atomic masses [27]. The 20th century was significant in terms of science since it saw the development of nuclear and particle physics and the discovery of subatomic particles [76]. NT was used by ancient people from the 4th century AD, according to historical records.

The Lycurgus Cup, a roman cage cup made of dichroic glass, is a classic example of NT in practice [62]. When the source of light and the observer are on the same side, it emits a green color and a bright red color when the viewer and the light source are on opposite sides. [67, 156]. This unusual effect was caused by two distinct silver (Ag) and gold nanoparticles (Au NPs). The green reflection comes from the Ag particles, whereas the red comes from the gold (Au). It is said to be the only surviving antique glassware with remarkable optical features [77]. According to medieval European artisans, adding gold chloride ($AuCl_3$) to molten glass gave it a reddish tinge [133], while silver nitrate ($AgNO_3$) gave it a yellowish tint [60]. During the 16th to 18th centuries, this method reached its pinnacle, resulting in creating some of the most magnificent stained glass in the world [22, 97]. However, the craftsmen were unaware of the scientific explanation for these beautiful hues at the time. Scientists later revealed that Au and silver nanoparticles (Ag NPs) in stained glassware operated as quantum dots (QDs), reflecting red and yellow light and enhancing the brilliance of the stained glass [24]. During the Renaissance period, around the 15th and 16th centuries, Italians employed nanoparticles (NPs) to make pottery. The Au and ruby red lusters could be explained by the existence of NPs of Ag, copper (Cu), mercury (Hg), and bismuth (Bi) in various proportions in the pottery [118].

Nanotechnology was also widely used in the Islamic world. The Islamic culture was also enamored by luster and strove to imitate pottery and art. The record states that the earliest luster beautifications were applied to glazed pottery in the Caliph's palace in Samara around 836–883 AD. A variety of metals was discovered during a chemical investigation of Islamic lustered potteries, out of which Cu and Ag NPs, in general, contributed to the coloration [142]. The ottomans manufactured "Damascus" saber blades made of cementite nanowires and carbon nanotubes (CNTs) that provided increased stability, toughness, and a sharp cutting edge until the 18th century [145]. Michael Faraday made one of the earliest attempts to investigate the properties of NPs [128] systematically. He investigated the characteristics and behavior of colloidal suspensions of 'ruby' Au in great detail, demonstrating that Au NP is responsible for various colors in solution [33]. The NT R&D Act of 2003 established the idea of NNI.

This chapter is an overview of the use of green NPs in various fields. Efforts have been made to have an in-depth overview of the utilization pattern and its potential benefits.

15.2 HISTORY OF NANOTECHNOLOGY

Richard Feynman, an American physicist and Nobel Laureate came up with "nanotechnology" in 1959. He gave a talk titled "There's Plenty of Room at the Bottom" at the American Physical Society's annual meeting at the California Institute of Technology. The underlined necessity of influencing and controlling things on a tiny scale in that lecture. He envisioned building a machine that could eventually build smaller machines down to the molecular level [39]. His predictions proved true, earning him the title of "Father of Modern NT" [59]. After 15 years, in a study published in 1974, Norio Taniguchi, a Japanese physicist, was the first to use and define NT [46]. After this, there was no looking back, and NT began to increase, and its potentials were applied to several disciplines for human benefits. NPs' harmful effects on living systems were caused by their small size, vast surface area, and propensity to create reactive oxygen species (ROS) [164]. NPs cause inflammatory reactions [38] and induce fibrosis in the living system [82]. They also trigger oxidative stress and alter electrochemical function [140]. Moreover, NPs suspended in the air due to contamination also adversely affect health [49, 141]. Thus, to minimize the harmful effects of NPs synthesized through conventional methods, scientists resorted to alternative and eco-friendly ways to synthesize NPs. The creation of green technology is a significant accomplishment in the realm of NT. Green NT is a green technology that incorporates green chemistry and green engineering principles, with the term "green" referring to nanomaterials (NMs) derived from plants. The key benefits of green NT are enhanced energy efficiency, less waste and greenhouse gas (GHG) emissions, and lower demand for non-renewable raw resources. Green NT provides a fantastic opportunity to prevent negative consequences before they arise [173]. These can be traced the history of green NT back to the National Nanotechnology Initiative (NNI) initiated by the United States of America under the leadership of Bill Clinton [55]. The NT R&D Act of 2003 established the idea of NNI [135]. The NNI had four goals, namely:

- Developing and expanding modern age NT R&D;
- Promoting the transformation of innovative technology into economic and public goods;
- Developing and maintaining educational materials and strengthening the framework and equipment needed to progress NT;
- Boosting the growth of NT in a responsible manner [71].

The fourth goal is 'sustained' via green NT by reducing or eliminating harmful substances generated during the synthesis of NMs [71]. Presently green NPs are synthesized using both plants and microbes. A first-time observation by Beveridge and Murray in the 1980s related to the use of $AuCl_3$ solution to suspend unfixed *Bacillus subtilis* cell wall. It can observe that Au NP was deposited extracellularly on the wall surface [42]. *Pseudomonas stutzeri* AG259, for the first time, was found to produce Ag NPs due to its reductive potential [129]. Another investigation states that *Pseudomonas aeruginosa* can generate a range of NPs intracellularly [159]. One of the first reports of fungus synthesizing Au NP was through *Verticillium* sp. [48]. Synthesis of palladium NPs was observed in *Chlorella Vulgaris* for the first time [11]. Gardea-research Torresdey's group initially reported Ag and Au NPs at the University of Texas at El Paso in the early 2000s by using *the Medicago sativa* plant. It offered up new and exciting possibilities for NP fabrication. In the developing field of nanobiotechnology, their work revealed a link between materials science and biotechnology [125]. In a more recent study, the potential of *Salvia Spinosa* to produce Ag NPs was reported [123]. Presently there has been an increase in awareness of green NPs, and their uses are increasing in several industries.

15.3 GREEN MANUFACTURING PROCESSES FOR BIO-NANOPARTICULATE MATTERS

The compelling reason behind the production of green nanomolecules is that these are both energy-saving and economical techniques considering the crucial circumstances of sustainable development. This technology also reduces the production of pernicious waste materials, which will safeguard our atmosphere rather than ecosystems. The green NPs are extracted from natural sources like plant extracts, algae, bacteria, fungi, yeast, and viruses. Here, we are discussing mainly how plant materials are used to manufacture green NPs. Plants are a rich source of phytochemicals, biopolymers, proteins, nano-cellulose, reducing agents, and metals along with their compounds which can draw out from disparate anatomical fragments like a few somatic and reproductive areas from the plant body and even by utilizing the whole individual.

The entire plant body of aquatic weed *Salvinia molesta* is used to retract the Au NP. After accumulating a specific amount of this particular freshwater hydrophyte, the undamaged, developed, and healthy aerial and submerged portions of the plant were taken, cleaned properly in normal water, and sterilized using saline water. The samples are dried at 105°C before taking their weight. About 1 gm of plant material is taken with 100 ml distilled water to boil for 5 minutes [2]. The filtration is done with Whatman no. 42 filter paper and is kept for refrigeration at 4°C [43–45]. The competence of the solution is retained for up to 3 days, and it can analyze through Reconnoitery experiments. The analytical reagent grade Chloroauric acid ($HAuCl_4$) is used to prepare a 10^{-3} M aqueous Au solution. The brown bottles are appropriate to store the produced Au NPs by wrapping them in. It needs to be veneered with dark paper. Characterizing of those Au NPs is done through various processes like UV-Visible Spectroscopy, studies of Fourier Transform Infrared Spectroscopy (FTIR), Energy Dispersive X-Ray (EDAX), Selected Area Electron Diffraction (SAED), and Scanning electron microscopy (SEM) or Transmission electron microscopy (TEM) [1]. *Pistia stratiotes* also aim for Au NPs extraction in the same way as it has been done from *Salvinia molesta* [9].

Ag-NPs can be synthesized from *Eichhornia crassipes* (presently the most troublesome aquatic weed). Those particles are both the reductant and coating agent within an aqueous medium. Differences in their efficiency are also observed according to the NP's variation in its optical and morphological properties [102]. The ultraviolet radiation promotes the percentage of chemical reactions combining the Ag molecules and the leaf essence of *E. crassipess*. At the same time, the Plasmon vibrations excite the solution showing color variation in various shades of yellow during a concise time duration of 5 minutes only. The NPs are validated by using UV-visible spectroscopy, TEM, X-ray diffraction (XRD) spectrometry, and Energy Dispersive X-ray (EDX) [64]. AuNPs also be drawn out from this invasive species.

The seeds of *Salvia Spinosa* were taken and sprouted in *in-vitro* conditions to get Ag-NPs [123], Pelargonium *graveolens*, *Salvia officinalis, Lippia citriodora, and others* can also be used for AuNPs squeezing [36], *Eucalyptus macrocarpa. Psidium guajava, Terminalia catappa,* and others [173]. Some plants like cashew nut, neem [17, 19, 40, 87], *Aloe vera* [173], etc., also provide bimetallic NPs (Au-Ag).

Unconventional approaches like water and supercritical carbon dioxide are explored as the substituted reaction media of organic solvents [162, 163]. "Hydrothermal approach" is the most approved technique among [91]. The warmed and excited green chemical kinetics are also investigated for elevating nano-molecules and plating critical articles [3]. Moreover, the absorbed sunshine [175], microwave power is also utilized to manufacture NPs [111]. There are some biosynthesis techniques are mentioned below.

15.3.1 MICRO-EMULSION TECHNIQUE

It is a resourceful procedure as it helps to manage particle's different characteristics like its expanse, shape, architecture, and consistency [58, 122] by providing variation in its occurrence like water-in-oil (W/O), bicontinuous structure, sponge phase, and through various dispersed phase emulsions [94]. Two main models are focused on their working principle: i) LaMer diagram and ii) the thermodynamic stabilization of the particles [81]. It can also induce various types of NPs like metals, metal oxides (MO), iron oxide (Fe_2O_3.FeO), colloidal silver chloride (AgCl), nanocrystalline titanium dioxide (TiO_2), aluminum oxide (Al_2O_3), and many others by using this method [12, 14, 21, 57, 83, 183].

15.3.2 ADDITIVE MANUFACTURING METHOD

These 3D printing techniques are more advantageous in terms of time efficiency, requirements, money-saving, and acquiescence, using for fabrication and biomedical industry at a greater magnitude during recent times [172]. A practical model can even mitigate the expenditure, pollution, and energy by 170–593 billion US dollars, 130.5–525.5 metric tons, and 2.54–9.30 joule respectively, within 2025 [47]. Discrete practices are involved within this technique as per requisite or for which purpose it is used. The advanced 3D nano-plasmonic architectures' peer-group printing deploys the spatial nanometer resolution through electron-stimulated responses within the direct-write fabrication of 3D metallic nano-designs while the tissue engineering is applying 2-photon-based nanofabrication process with self-restrained electrospinning [79].

15.3.3 NANOSUSPENSION METHOD

Many botanical medicines show its limitation regarding molecular mobility, assimilation rate, water solubility, and lesser *in vivo* capacity. Nanosuspension is an excellent applied method to solve this problematic issue of herbal drug production and delivery system [66]. The sonification is done to solvate the prepared plant solution like seeds of *Coriandrum sativum* (2.5 g) with the acetone and ethanol mixture (15 ml) at 3:1 proportion only for 60 seconds, followed by administering that mixture to different polyvinyl alcohol solutions. The produced NPs are finally kept cool to –18°C, and the lyophilizer is operated to make the desired one into dry dust [100].

In addition to that, other ways such as Rotary-evaporated film ultra-sonication method, Ionic Gelation method, Emulsion Solvent Evaporation, Dialysis method, Rapid prototyping, Sol-Gel technology, etc., and sometimes an integrated approach are also used to generate the green NPs. We need to concentrate on supplemental turning out of these particles during a short time and with profitable strategies.

15.4 USE OF NANOPARTICLES IN VARIOUS DOMAINS

15.4.1 AGRICULTURE

Currently, agriculture is dealing with some significant challenges, standing out to be an intervening factor for this sector. Drastic climate changes decrease soil fertility, macro and micronutrient deficiency, and excessive usage of fertilizers and pesticides.

In this scenario, Green NT has an immense role in uplifting the present agricultural systems [4]. NPs have varied applications in the field of agriculture, namely pesticides delivery [113], delivery of nutrients [72], biofertilizer formulation [146], supplying genetic materials for crop improvement [177], and plant disease management [178]. The declining awareness of the farmers and overuse of chemicals is taking hard on Agriculture Industry. The commonly used NPs used here include Ag, nano-aluminosilicates [34], Titanium oxide [92], and CNM [108].

The use of nanopesticides has inconspicuously increased crop productivity [130]. A stable nano-pesticides-Biofenthrin using polymer stabilizers like polyvinyl pyrrolidone, polyvinyl alcohol, and polyacrylic acid, has been successfully formulated [88]. Nanosilica is obtained from various shell walls of diatoms [99] which can be potentially treated as pesticide [37].

NPs for disease management with specific antimicrobial properties prevent microbial infestations. To name a few, cobalt and nickel ferrites [148], Cu NPs exhibit strong anti-fungal properties [63]. Chitosan NPs, Zinc oxide (ZnO), and silica are quite effective against the viral diseases-Mosaic virus for Tobacco, Potato, and Alfalfa [165]. NT is also coming up with a good enhancement in the field of Agriculture with nano-fertilizers. Nano-fertilizers are made from different plant parts encapsulated with NM [158]. Different forms of nano-fertilizers are available in the form of Nitrogen(N), Phosphorus(P), Calcium(Ca), Magnesium(Mg), and Potassium(K), Manganese(Mn), etc. [19]. Bio fertilizers-based nano-fertilizers are equally effective for crop development programs as they positively interact with microbes and organic compounds, making the latter bioavailable to plants [143]. In one such study, the effects of PGPR containing nano-biofertilizers towards fatal fungal and bacterial pathogens within the rhizosphere of the leguminous crops [61].

Nanobiotechnology has also revolutionized the field of seed technology. Seed quality is a significantly measurable attribute of Agriculture, and it comprises the entire genetic complement of the crop. Studies from recent literature have shown that NPs have increased germination, vigor, and quality of seeds like groundnut, onion, lettuce, spinach, tomato, etc. For faster germination, CNTs penetrate more deep seed layers and support water up taken by them [151].

Nano-biosensors are another domain of NT that has revolutionized farming systems to a great extent. NPs like Au, Ag, Si, Pt are commonly used as biosensors [29, 30]. Fluorescent Silica NPs associated with antibodies can identify the presence of plant pathogens like *Xanthomonas axonopodis pv. Vesicatoria* [139]. Au NPs can be used to detect hidden infection of brown rot of potato [131]. Besides the application of nano-biosensors, nanobiotechnology has a conspicuous role in the field of Agriculture. Nanobiotechnology is amalgamating molecular and cell biology leading to the development of outstanding crop varieties [74]. To revolutionize sustainable Agriculture NT, we need to prioritize the aspect of controlled green synthesis of NPs, the interaction of NPs with the plant system, and its adverse side effects on different environmental conditions [32]. Focusing on the right policies for developing a sustainable Agri-nanotechnology is of utmost priority, which includes the formulation of specific guidelines by the Food Safety and

Standards Authority, collaborative research for developing a better research system, proper evaluation for biosafety of NPs, and most importantly, educating farmers about this novel strategy.

15.4.2 FABRICS

The textile industry has a high dependency resource rate globally as it exploits considerable amounts of energy, water, and various hazardous chemicals. The current situation has induced some issues regarding the sustainability of textiles due to major answerability on the environment. So, researchers have come up with the best possible alternative for the long-term sustenance of the textile industry. Currently, green chemistry has emerged as an effective tool for keeping this industry sustainable. Green chemistry has exceptionally contributed to the development of alternative biodegradable chemicals which can be used as washing and wetting agents. Out of several NP synthesis techniques, the green synthesis technique stands out to be most effective in controlling particle size and morphology.

In comparison to other conventional techniques, this technique is relatively amicable. Papaya peel-derived Ag NPs pose a practical example in developing fabrics due to their potential antibacterial activity [30]. The remarkable deceleration in reaction time with fruit peel extract led to significant results that have enabled NP biosynthesis to give a tough competition with any other strategies for forming NPs that are more reproducible [149]. According to a recent study, biosynthesized Ag NPs from *Acalypha indica* leaf extract were coated over cotton fabric [51]. Besides, the Ag NPs coated cotton fabric flaunted significant antimicrobial activities [52]. Amongst the different metal oxide NPs used in textile finishing, silver oxide (Ag_2O) has speculated more sustenance, especially for outstanding antimicrobial properties. Papaya peel-derived Ag NPs, have been amalgamated into fabric processing, and the manufacturers are providing textiles free from ruination by microbes [5]. These once again proves an extraordinary green revolution in NT for a better textile industry tomorrow.

15.4.3 COSMETICS

Cosmeceuticals are now the fastest-growing ancillary of the personal care industry with promising economic growth-besides, immense benefits of NPs. The two most crucial tools – liposomes [127] and niosomes [25] play the roles of delivery vehicles in the cosmetic industry. Structures like solid lipid NPs and nanostructured lipid carriers have proven superior to liposomes [150]. Moreover, nanostructured lipid carriers are prospective as next-generation cosmetic delivery agents that can enhance skin hydration, bioavailability, and biostability of the agent and occlusion in a more controlled manner [109, 120]. Nanocrystals and nanoemulsions are also pioneers in the cosmetic industry [176]. Dendrimers which are nanosized and radially symmetric molecules with a homogeneous structure continues to be one of the vital necessities of cosmeceuticals. Several patents have been filed for the same [1, 18]. ZnO NPs – a major constituent of all sunscreens block ultraviolet rays minimizing the white coating on the skin [157]. Ivy plants generate most of the NPs used in sunscreens. Based on current research surveys, ivy NPs are more effective than oxide NPs in preventing ultraviolet rays [179]. All skin creams utilize proteins from stem cells to inculcate anti-aging properties [157]. These proteins are coated with liposome NPs which merge with the skin membrane, thereby allowing delivery of the proteins. Skincare lotions are just an amalgamation of nutrients condensed in NPs in liquid suspension, leading to nanoemulsion formation. The smaller size of NPs allows the better penetration into the skin [73] when compared to particles in conventional emulsions, thereby enriching the skin layer with maximum nutrients.

15.4.4 WATER POLLUTION MANAGEMENT

In the present scenario, water quality and water availability have been found as one of the main obstacles that the human race is confronting. Water contamination is caused by various factors, including discarding of garbage, oil spillages, see page of different fertilizers, weedicides, insecticides, manufacturing spin-offs, fossil fuels extraction, and burning [80]. In this circumstance, NT presents an eclectic array of abilities and technologies to enhance the attribute of prevailing environs [136]. NT possesses three critical uses in the spheres of natural environs [182], such as (Figure 15.1):

- Remediation and decontamination of polluted substances;
- Perceiving and recognition of contamination; and
- Preclusion of contaminations.

NMs possess more excellent responsiveness, capability, and a perceptiveness for heavy metals and other impurities. The reason for utilizing NMs is the elevated receptiveness, heftier exterior interaction, and enhanced clearance ability. Several NMs have been used to treat water pollutants [183], such as CNTs, biopolymers, zerovalent iron (ZVI), self-assembled monolayers, etc.

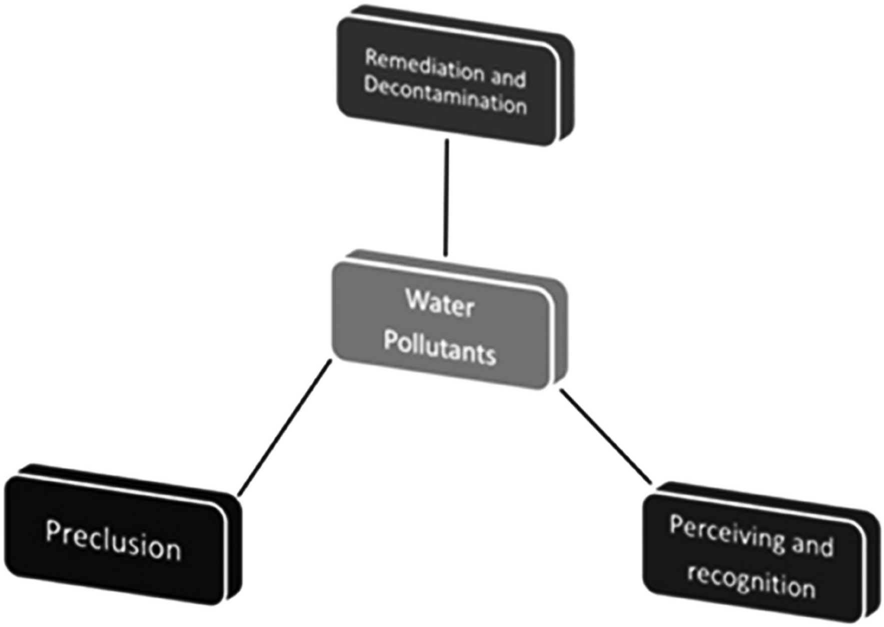

FIGURE 15.1 Key uses of NT in water pollution control.

The pumping and treating approach were applied to mitigate water pollutants till 1998. An alternative approach to mitigate water is through applying a permeable reactive barrier (PRB). It cleanses sub-surface groundwater. In addition to that, it mitigates devoid of the necessity to bring in the water towards the surface. PRBs are utilized to cleanse contaminants, for instance, chlorinated hydrocarbons (HCs), aromatic N_2 compounds, Polychlorinated biphenyls (PCBs), insecticides, and chromates [183]. The use of PCBs is costly. But it observed that some ZVI, i.e., zerovalent metals such as Fe, purported to be a filtering substance of PBR, can manage or ease hazardous toxins present in the water in massive amounts [70]. The tiny unit size establishes nano-Fe, which is proficient in multipurpose usage intended for remedial reasons. Usage of nano-iron along with the PRBs has been shown efficient. Other metals like Zn might replace Nano-iron, and Sn can lessen impurities like Fe. Even two metal alloys, i.e., Fe and FeNi–Cu are engaged to vitiate C_2HCl_3 (Trichloroethene) [115].

Ferritin, a Fe-containing protein that is present in plants and animals. It can convert Fe atoms into ferrihydrite NPs. In visible daylight or solar radiation, ferritins can reduce toxic metals and chlorocarbons [124]. There are countless other examples of NT applications in water treatment in addition to the methods illustrated before., such as Self-Assembled Monolayers on Mesoporous Silica, dendrimers (SAMMS), Single Nanoparticle Enzymes (SEN), etc. [183].

In Recent Times, Green, and biologically synthesized NPs have been reconnoitered for sewage remediations, treatment works, etc., accompanied by other water decontamination tools to diminish or eradicate the hazardous tainted components present in water reserves [155]. However, the magnitude of regulations, steadiness, accretion, and alleviation are yet regarded as constant encounters for commercial usages of biogenic NPs in alleviating overflows of water contaminants. There are three nanocomponents such as (1) nano-adsorbents, (2) nano-catalysts, and (3) nano-films which are playing essential roles in exclusions of heavy metals [170] along with the dilapidation of organic, inorganic, radioactive, and therapeutic contaminants, nitrogen compounds), nitrate (NO_3^-), Phosphate (PO_4), and other hazardous dyes [10, 11, 85, 181].

15.4.5 WASTE MATERIAL MANAGEMENT

Wastewater is the spinoff of various water utilities such as domestic utilizes, such as bathing, cleaning utensils, washing clothes, and cleaning out the toilet. In addition, water coming out from the industries is also regarded as wastewater treatment. Although developed drainage systems were well before the 18th century, wastewater disposal is a relatively new activity. Wastewater or sewage treatment is the procedure and skill applied to eliminate many of the impurities to make sure sturdy environs that help suitable civic wellbeing [8]. Controlling wastewater involves managing wastewater to keep the environs safe for the public's monetary, societal, political comprehensiveness, and healthiness [96].

Nowadays, NT is considered a critical practice to treat wastewater to detect and exclude several contaminants [12]. The usage of NT in managing wastewater is achieving impetus worldwide due to the exclusive characteristics of NMs and higher congeniality amongst the accessible typical treatment processes for treating wastewaters [107]. Different nanotechnological approaches like photo-catalysis, nano-filtration, adsorption, and oxidation of electro-chemicals encompass different various technical domains (Figure 15.2).

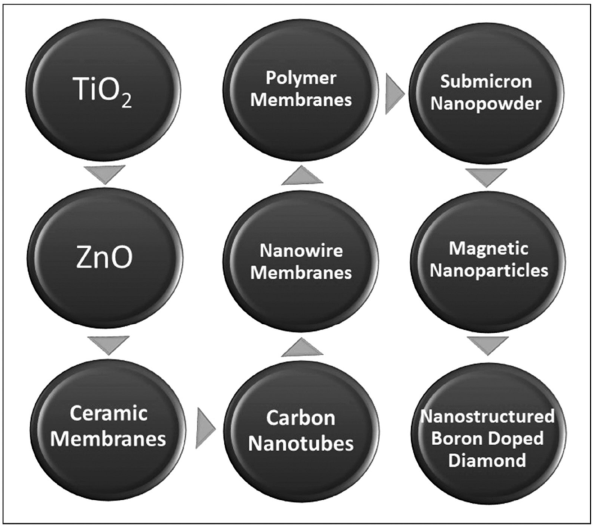

FIGURE 15.2 Different components of green nanoparticles used in waste material management.

NPs are utilized as adsorbents, nanosized zerovalent ions, or nanofiltration membranes, causing the amputation of pollutants from wastewater [114]. While NPs used as catalysts for oxidation of photo-chemical results in the obliteration of impurities present. Nanoscale materials are utilized to treat wastewater. Nanoscale materials consist of four classes [168]: dendrimers, metal-containing NPs, zeolites, and carbonaceous NMs.

Nanotechnology also uses dendrite polymer materials in wastewater treatment and purification. Dendrite polymers comprise random hyperbranched polymers, dendrigraft polymers, dendrons as well as dendrimers [41]. Dendrimers vary in shapes and size ranges 2–20 nm [171]. It has been observed that dendrons with a multi-functional mainstay form a dendrimer structure. Dendron-enhanced ultrafiltration techniques having poly-amido-amine Dendrimers combining with Ethylene Diamine (present as core molecules) and amine (NH_2) group's (at the terminal end) can produce Cu^{++}, which reduces toxic components of wastewater [31, 32]. Ag-NPs show elevated antimicrobial activity [168].

NPs of oxides of metals, namely TiO_2, ZnO, and cerium dioxide (CeO_2), which possess greater reactivity and photolytic properties than others, can cause the purification of wastewater [75]. Magnesium and Magnesium oxide (MgO) NPs are inhibitory to Gram-positive and Gram-negative bacteria [161]. Pd/Fe_3O_4 nano-catalysts have also been observed to treat wastewater processes [56]. Zeolites are utilized to remove heavy metals present in wastewater like – Cr^{3+}, Ni^{2+}, Zn^{2+}, Cu^{2+}, and Cd^{2+} from the wastewaters [7]. Carbon NPs, nanotubes, nano-diamonds, and nanowires are act as sorbents and possess higher capability and specificity, intended for organic solutes present in the wastewater. They are steady, having inadequate receptiveness used as potent antioxidants [171].

15.4.6 MEDICAL TRENDS

It is essential to be explored more to protect human life from undesirable health-related disorders. Green NT ensures greater feasibilities in the medical field, significantly influencing the drug delivery system (DDS) and surgery-associated affairs. Including all the green NPs, the Ag and Au NPs are explored chiefly yet. Despite an emerging area, the boon of NT assists our medical system in several realistic ways. Massive investigations are going on for variegated algal, plants, and bacterial species. We can extract copious NPs showing antimicrobial properties and can be used for other medical purposes. It should be anticipated that different sources for varying NPs gaining and those NPs are essential to fight against diseases. So, biodiversity-rich countries like India, Brazil, Mexico, and others should invest more to invent convenient NPs which will be availed for the betterment of human civilization. The nano-material and nano-devices are currently employed at a noteworthy scale in nano-medicinal trends, which are presently [86] by dividing into distinct groups from first to fourth generation nanosystems. The last generation's achievements have paved the path of human organs renewal [93]. Even though the procedure is overpriced and tedious, the newly invented nano-drug molecules help to increase the shelf life, permeability, and mitigate the virulence [26]. Ag-NPs and Au NPs are also used in gene delivery systems [91]. The versatility, like recognition, distribution of well-planned remedy, etc., is the principal focus of these types of nano-drug delivery systems [84, 132, 134, 180]. The impenetrable anti-cancerous drug Sorafenib can be used via nano-carriers [166].

The newly advanced cartilage adjustment nano-materials like stainless steel, bioactive bone cement, titanium alloy, calcium phosphate apatite, etc., are more biocompatible, contributing to better chances for limb implantations [86], and those can even be handled particulars from outside via the internet or exterior operators [116].

The assemblage of more particles diagnoses the tumor site, while magnetically operating diatom frustules also facilitate the transportation of tiny anti-cancerous particles. Frustule modifications with different natural and inert bio granules ameliorate its service by making it an advanced nano-structured appliance. Nano-carriers such as obtained from diatoms help to reach most of the target site within the affected area of the human body, automatically reducing the chemical dosages [166]. It (Au nanoshells) can destroy tumors gradually through chemotherapy. The PH-specific NPs are more effective for that kind of treatment. Platinum NPs are also taken to cure cancer in various parts of the human body [121]. Au NPs and Ag NPs from pollen solution of *Phoenix dactylifera* create good impacts for MCF-7 type of cancer in the mammary gland treatment by destructing units related with the apoptosis and triggering the disease all over the body [15] while *Nostoc* and *Anabaena* sp. Colonies' extracted Ag NPs are used as anti-cancerous agent [20]. The human infected cells of Leukemia (lymphoblastic Leukemia mainly) can be obstructed by applying those Ag NPs [137]. *Desertifilum* sp. also permits Ag NPs to inhibit a higher level of different colon, liver, and breast cancer cell lines propagation at competent concentrations [54]. Un-uniformed shaped ZnO nanoparticles (ZnO NPs) from *Ziziphus nummularia* leaves (distilled portion) reduces the possibility of cervical cancer at the rate of more than 50% [117] and the combination of 80 μg ml^{-1} including large granular lymphocytic cells of murine in ZnO NPs of *Laurus nobilis* leaves check the spreading of the mutant cancerous cells [174].

In addition to cancer, DDS is also concentrated to cure nerve diseases such as Alzheimer's, etc., primarily Human Immuno-deficiency Virus (HIV) infection [93]. Discrete metallic and its oxides NPs are like iron oxide (Fe_2O_3. FeO), ZnO, platinum (Pt), Cu, etc., from plant materials are popular in DDS [112]. The antimicrobial activity of copper oxide NPs is used both as a surface disinfectant and injury bandage [53]. The dopamine-modeled Fe_2O_3. FeO NPs from diatoms lead to a far better drug carriage system, including around 22 weight percentage drugs stacking potentiality and safer for drugs more than two weeks [90]. AuNPs from *Lippia citriodora*, *Salvia officinalis*, and *others serve* as equalization and reducing mediums [36] and carry antibiotics [144]. The combined particles of ZnO NPs from *Anabaena* sp. with shinorine work as innocuous sunscreen service [54]. A more significant antioxidant influence than other nutritious phytochemicals like citric acid is found from the Au NPs of freshwater algae – *Phormidium* sp. Furthermore, green Au NPs from *Phormidium* sp. and *Coelastrella* sp. are applied for bio-labeling and detecting deoxyribonucleic acid (DNA) [106]. Establishing the electro-ballistic hydrogen peroxide (H_2O_2) biosensors by glassy carbon electrode requires zinc nanoparticles (Zn NPs) as observed from *Corymbia citriodora* [184].

Ag-NPs from the water hyacinth stalk and *Synechococcus* sp. offer antimicrobial activities against a few gram-positive and negative bacteria like *Staphylococcus aureus*, *Pseudomonas fluorescens*, *E. coli*, etc. [167]. Those NPs hinder the membrane penetration, cellular respiration by allocating sulfur protein, dispersing the electrochemical procedure of ATP synthesis, and fracturing the outer cell wall membrane [50, 89, 103].

The antimicrobial activities denote those highly responsive components with a greater surface area, allowing them to bind more with the bacterial surface receptors by their ligands [28].

Au NPs from *Euphorbia hirta* and *Annona muricata* have antibacterial characteristics, while Ag NPs from *Jasminum auriculatum* [13] and *Melia azedarach* leaves [69] behave as antifungal agents. It can also treat dermatological lesions, inflamed injuries, blisters with Ag NPs within a lesser duration, and layering the contact eye lenses. Moreover, Ag NPs have immense power to balance the shear bonds, making them appropriate for use in both dental and orthopedic transplantation [110]. A diabetic sufferer would get a remedy with strong microbicidal effects of Ag NPs of Anabaena sp. It performs against some drug-resistant micro-organisms like *Klebsiella pneumonia*, etc. [154]. The existence of phytochemicals like amino acids, flavonoids, etc., of Zn NPs from the liquid solution of *Barleria gibsoni* leaves offers reducing and defensive methods [147]. It can even treat the unhealed ulcers with *Strychnos nux-vomica's* Zn NPs due to its excessive restorative feature giving decreased immunosuppressive responses [160].

The remedy for DNA and other cellular damages can do customized drug therapy with the help of somewhat lengthy but advanced green NT. Nanorobots are already invented, and these can be used in different surgeries that would be without any scars within the body and 1,000 times more accurate than the present serrated scalpel [6].

Few common plants' leaves like *Rosa Officinalis, Cynodon dactylon, Azadirachta indica*, etc., are used to yield non-contaminating, money, and power-saving, and somewhat pure green CNTs [169]. Those are advantageous for their greater capacity of drug uptake, higher conductivity, and lightweight. It shows lower side effects after chemotherapy and can distinguish between normal and malignant cells. An undeviating mechanism for hitting the target site in the mammalian cells during the treatment gives a well-advised recovery through cytoplasmic transportation of the payload [78, 105]. The blood-brain barriers always block the path by which the drug can reach out to the tumors, but CNTs can go there and heal it [16]. The CNT is a convenient option for applying the drug for cancer treatments (drug delivery) in lymphatic organs.

Hence, it can assume that the empirical approach of green NT will gradually design a revolutionary era in medical history.

15.5 CHALLENGES

The classical designs are trying to substitute with the additive processes for green NPs manipulations. Additive manufacturing is restricted to its small range of few polymers and metal powders only. The labyrinthine plan of action of that green biogenesis creates it incurious [68]. Inconsistent Ph, temperature, reducing agents, reagents' concentration, reaction, and incubation time are followed according to the material and architectural configuration of NPs. For example, Ag nano-molecules can be found at room temperature from *Myristica fragans* fruit pericarp while Au NPs demand 90°C, coerced from the same organ of *Terminalia berillica*. In addition, leaves are the only benign source for NPs extraction as it does not affect any plant as much as after removing any other body parts like roots, fruits, etc. [23]. Lack of knowledge is another primary concern. It cannot utilize the end products solely. Many high-priced and harmful products require to obtain the particles, and the target for cost efficiency cannot be achieved [172]. It cannot also be judged the harmful impacts of few NPs still now. The unpleasant consequences are there when the nano-herbicides, pesticides, or fertilizers are applied. Apoptosis, stress sensitivity, and different physiological metabolisms are disrupted in Asian Rice plants by Au NPs and Ag NPs [98]. Much better communication and understanding have to be shared among researchers, administrators, industries, and workers to replete the gap area regarding those disadvantages [173]. It is an emerging area on a global scale, so a lot more investigations are necessitated for transversing and aiming this area expertly. Moreover, there is a lack of proper infrastructure and laboratories for the experiment as it is still mainly in the demonstrative phase. The training purposes demand few expenses too, including some wastage due to uncertainty in its knowledge [65].

15.6 FUTURE PROSPECTS

Green NT can be crowned as the significant Industrial Revolution that supports sustainable solutions to varied Global issues [119, 126]. The primary consideration that makes NT a promising future is utilizing the least energy and most minor use of toxic compounds. Many innovations so far in this field have proved to be of great importance for the future. Besides, these discoveries indeed impose a positive impact on the global economy.

Some well-developed innovations include greener cars where the vehicles can run on non-fossil fuel energy instead of hydrogen fuel. Even there can be prospects of consuming fossil fuels by using nanocomposites (NCs), and also tire innovation can be made using different NMs. Green NT can promise a better future for the paper and packaging industry where cellulose can be involved in paper production. The use of nanotubes for transport and electronic applications has become an essential requirement of today and will be a necessary tool in the future as they bear high strength, low weight, low density, and are cost-effective [185].

Green NT opens another door of a globally important concept called “Green Economic” that is highly dependent on sustainable development. The conceptualization of the Green Economy has been established by the United Nations Environment Program (UNEP). This new concept of the green economy is expected to improve human wellbeing. The Green economy can play a significant role in changing society on a Global platform keeping Environment and Economy as two interfaces. At this juncture, Green NT has an influential role in assembling the precise functioning of NT, plant science, and chemistry and coming up with revolutionized products for mankind.

15.7 SUMMARY

The human population is taking a peak globally, and as a consequence, it is impacting our sustainable resources. In this scenario, Green NT has a crucial role to play as it can envisage sustainability. The principles of green chemistry influence the life cycle of nano-products, starting from design to disposal. It can be a novel strategy for humans and the environment that can revolutionize large-scale nano-synthesis procedures. The parameters on which green chemistry stands upon include reduced toxicity, biodegradable, and cost-effectiveness. It mainly aims to exploit the different properties of NMs. These solutions can reduce the renewable Energy source and improve power delivery systems to provide a better ecosystem and livelihood conditions. Green NT, an emerging technology, might meet particular challenges that include technical barriers, proper utilization of NMs, and regulatory policies for synthesis. The amalgamation of NT and green chemistry is gradually taking the right shape with technological advancements and can be considered a sustainable future of nano-synthesis. Undoubtedly, green nano-products

are based on clean energy applications. Moreover, the conjunction of plant sciences and NT has immense potential to evolve an attractive symbiosis between the green revolution and NT with realistic prospects. Thus, green NT should not refrain from providing only green solutions instead of adopting and adapting "green" in terms of overall human safety and healthcare. This tactful deliberation can magnify environmental and social wellbeing, health concerns, and cost savings, thereby maximizing the possibilities of future speculation and sustainability of this promising technological field.

KEYWORDS

- **carbon nanotubes**
- **energy dispersive x-ray**
- **Fourier transform infrared spectroscopy**
- **gold nanoparticles**
- **nanomaterials**
- **nanoparticles**
- **nanotechnology initiative**
- **selected area electron diffraction**

REFERENCES

1. Abbasi, E., Aval, S. F., Akbarzadeh, A., Milani, M., Nasrabadi, H. T., Joo, S. W., Hanifehpour, Y., et al., (2014). Dendrimers: Synthesis, applications, and properties. *Nanoscale Research Letters, 9*(1), 1–10, 247.
2. Abbasi, E., Milani, M., Fekri, A. S., Kouhi, M., Akbarzadeh, A., Tayefi, N. H., Nikasa, P., et al., (2016). Silver nanoparticles: Synthesis methods, bio-applications, and properties. *Critical Reviews in Microbiology, 42*(2), 173–180.
3. Abdelaziz, R., Disci-Zayed, D., Hedayati, M. K., Pöhls, J. H., Zillohu, A. U., Erkartal, B., Chakravadhanula, V. S., et al., (2013). Green chemistry and nanofabrication in a levitated leidenfrost drop. *Nature Communications, 4*(1), 1–10.
4. Acharya, A., & Pal, P. K., (2020). Agriculture nanotechnology: Translating research outcome to field applications by influencing environmental sustainability. *Nano-Impact, 19*(100232), 1–14.
5. Agarwal, R., Garg, N., Kashyap, S. R., & Chauhan, R. P., (2015). Antibacterial finish of textile using papaya peels derived silver nanoparticles. *Indian Journal of Fiber & Textile Research, 40*(1), 105–107.

6. Aithal, P. S., & Aithal, S., (2016). Nanotechnology innovations and commercialization: Opportunities, challenges, and reasons for delay. *International Journal of Engineering and Manufacturing, 6*(6), 15–25.
7. Alvarez-Ayuso, E., Garcıa-Sánchez, A., & Querol, X., (2003). Purification of metal electroplating waste waters using zeolites. *Water Research, 37*(20), 4855–4862.
8. Amoatey, P., & Bani, R., (2011). *Wastewater Management* (Vol. 2, pp. 1–22). Intech Open Access Publisher.
9. Anuradha, J., Abbasi, T., & Abbasi, S. A., (2015). An eco-friendly method of synthesizing gold nanoparticles using an otherwise worthless weed pistia (*Pistia stratiotes* L.). *Journal of Advanced Research, 6*(5), 711–720.
10. Arora, P. K., Srivastava, A., & Singh, V. P., (2014). Bacterial degradation of nitrophenols and their derivatives. *Journal of Hazardous Materials, 266*, 42–59.
11. Arsiya, F., Sayadi, M. H., & Sobhani, S., (2017). Green synthesis of palladium nanoparticles using *Chlorella vulgaris*. *Materials Letters, 186*, 113–115.
12. Ayyub, P., Multani, M., Barma, M., Palkar, V. R., & Vijayaraghavan, R., (1988). Size-induced structural phase transitions and hyperfine properties of microcrystalline Fe_2O_3. *Journal of Physics C: Solid State Physics, 21*(11), 2229–2245.
13. Balasubramanian, S., Kala, S. M. J., & Pushparaj, T. L., (2020). Biogenic synthesis of gold nanoparticles using *Jasminum auriculatum* leaf extract and their catalytic, antimicrobial, and anticancer activities. *Journal of Drug Delivery Science and Technology, 57*(101620), 1–14.
14. Bandow, S., Kimura, K., Kon-No, K., & Kitahara, A., (1987). Magnetic properties of magnetite ultrafine particles prepared by W/O microemulsion method. *Japanese Journal of Applied Physics, 26*(5R), 713–717.
15. Banu, H., Renuka, N., Faheem, S. M., Ismail, R., Singh, V., Saadatmand, Z., Khan, S. S., et al., (2018). Gold and Silver nanoparticles biomimetically synthesized using date palm pollen extract induce apoptosis and regulate p53 and Bcl-2 expression in human breast adenocarcinoma cells. *Biological Trace Element Research, 186*(1), 122–134.
16. Beg, S., Rizwan, M., Sheikh, A. M., Hasnain, M. S., Anwer, K., & Kohli, K., (2011). Advancement in carbon nanotubes: Basics, biomedical applications and toxicity. *The Journal of Pharmacy and Pharmacology, 63*(2), 141–163.
17. Bhatt, R., De Vries, P., Tulinsky, J., Bellamy, G., Baker, B., Singer, J. W., & Klein, P., (2003). Synthesis and *in vivo* antitumor activity of poly(l-glutamic acid) conjugates of 20S-camptothecin. *Journal of Medicinal Chemistry, 46*(1), 190–193.
18. Bilal, M., & Iqbal, H., (2020). New insights on unique features and role of nanostructured materials in cosmetics. *Cosmetics, 7*(2), 1–24. https://doi.org/10.3390/cosmetics7020024.
19. Bindraban, P. S., Dimkpa, C. O., & Pandey, R., (2020). Exploring phosphorus fertilizers and fertilization strategies for improved human and environmental health. *Biology and Fertility of Soils, 56*(3), 299–317.
20. Bin-Meferij, M. M., & Hamida, R. S., (2019). Biofabrication and antitumor activity of silver nanoparticles utilizing novel *Nostoc sp*. Bahar M. *International Journal of Nanomedicine, 14*, 9019–9029.
21. Boutonnet, M., Kizling, J., Stenius, P., & Maire, G., (1982). The preparation of mono-disperse colloidal metal particles from microemulsions. *Colloids and Surfaces, 5*(3), 209–225.
22. Capobianco, N., Hunault, M. O., Balcon-Berry, S., Galoisy, L., Sandron, D., & Calas, G., (2019). The Grande rose of the Reims cathedral: An eighth-century perspective on the color management of medieval stained glass. *Scientific Reports, 9*(1), 1–10.

23. Castillo-Henríquez, L., Alfaro-Aguilar, K., Ugalde-Álvarez, J., Vega-Fernández, L., De Oca-Vásquez, G. M., & Vega-Baudrit, J. R., (2020). Green synthesis of gold and silver nanoparticles from plant extracts and their possible applications as antimicrobial agents in the agricultural area. *Nanomaterials (Basel, Switzerland)*, *10*(9), 1763. https://doi.org/10.3390/nano10091763.
24. Chan, C., (2008). *From Nanotech to Nanoscience Science*. Science History Institute. https://www.sciencehistory.org/distillations/from-nanotech-to-nanoscience (accessed on 9 July 2022).
25. Chen, S., Hanning, S., Falconer, J., Locke, M., & Wen, J., (2019). Recent advances in non-ionic surfactant vesicles (niosomes): Fabrication, characterization, pharmaceutical, and cosmetic applications. *European Journal of Pharmaceutics and Biopharmaceutics: Official Journal of Arbeitsgemeinschaft Fur Pharmazeutische Verfahrenstechnik E.V, 144*, 18–39.
26. Cho, K., Wang, X., Nie, S., Chen, Z. G., & Shin, D. M., (2008). Therapeutic nanoparticles for drug delivery in cancer. *Clinical Cancer Research: An Official Journal of the American Association for Cancer Research, 14*(5), 1310–1316.
27. Constable, E. C., (2019). Evolution and understanding of the d-block elements in the periodic table. *Dalton Transactions, 48*(26), 9408–9421.
28. Cruz, D. M., Tien-Street, W., Zhang, B., Huang, X., Vernet, C. A., Nieto-Argüello, A., Cholula-Díaz, J. L., et al., (2019). Citric juice-mediated synthesis of tellurium nanoparticles with antimicrobial and anticancer properties. *Green Chemistry: An International Journal and Green Chemistry Resource: GC, 21*(8), 1982–1988.
29. Dar, F. A., Qazi, G., & Pirzadah, T. B., (2020). Nano-biosensors: Nextgen diagnostic tools in agriculture. In: Hakeem, K., & Pirzadah, T., (eds.), *Nanobiotechnology in Agriculture, Nanotechnology in the Life Sciences* (pp. 129–144). Springer.
30. Deng, H., McShan, D., Zhang, Y., Sinha, S. S., Arslan, Z., Ray, P. C., & Yu, H., (2016). Mechanistic study of the synergistic antibacterial activity of combined silver nanoparticles and common antibiotics. *Environmental Science & Technology, 50*(16), 8840–8848.
31. Diallo, M. S., Christie, S., Swaminathan, P., Johnson, J. H., & Goddard, W. A., (2005). Dendrimer enhanced ultrafiltration. 1. Recovery of Cu (II) from aqueous solutions using PAMAM dendrimers with ethylene diamine core and terminal NH_2 groups. *Environmental Science & Technology, 39*(5), 1366–1377.
32. Dixit, R., Malaviya, D., Pandiyan, K., Singh, U. B., Sahu, A., Shukla, R., & Paul, D., (2015). Bioremediation of heavy metals from soil and aquatic environment: An overview of principles and criteria of fundamental processes. *Sustainability, 7*(2), 2189–2212.
33. Dreaden, E. C., Alkilany, A. M., Huang, X., Murphy, C. J., & El-Sayed, M. A., (2012). The golden age: Gold nanoparticles for biomedicine. *Chemical Society Reviews, 41*(7), 2740–2779.
34. Duhan, J. S., Kumar, R., Kumar, N., Kaur, P., Nehra, K., & Duhan, S., (2017). Nanotechnology: The new perspective in precision agriculture. *Biotechnology Reports, 15*, 11–23.
35. Edwards, P. P., Egdell, R. G., Fenske, D., & Yao, B., (2020). The periodic law of the chemical elements: 'The new system of atomic weights which renders evident the analogies which exist between bodies' [1]. *Philosophical Transactions. Series A, Mathematical, Physical, and Engineering Sciences, 378*(2180), 20190537. https://doi.org/10.1098/rsta.2019.0537.
36. Elia, P., Zach, R., Hazan, S., Kolusheva, S., Porat, Z. E., & Zeiri, Y., (2014). Green synthesis of gold nanoparticles using plant extracts as reducing agents. *International Journal of Nanomedicine, 9*, 4007–4021.

37. El-Naggar, M. E., Abdelsalam, N. R., Fouda, M. M., Mackled, M. I., Al-Jaddadi, M. A., Ali, H. M., Siddiqui, M. H., & Kandil, E. E., (2020). Soil application of nano-silica on maize yield and its insecticidal activity against some stored insects after the post-harvest. *Nanomaterials, 10*(4), 739. https://doi.org/10.3390/nano10040739.
38. Elsabahy, M., & Wooley, K. L., (2013). Cytokines as biomarkers of nanoparticle immunotoxicity. *Chemical Society Reviews, 42*(12), 5552–5576.
39. Feynman, R. P., (2012). *There's Plenty of Room at the Bottom: An Invitation to Enter a New Field of Physics* (pp. 26–35). Boca Raton, FL, USA: CRC Press.
40. Fonseca, C., Simoes, S., & Gaspar, R., (2002). Paclitaxel-loaded PLGA nanoparticles: Preparation, physicochemical characterization and *in vitro* anti-tumoral activity. *Journal of Controlled Release, 83*(2), 273–286.
41. Frechet, J. M., & Tomalia, D. A., (2002). *Dendrimers and Other Dendritic Polymers* (p. 688). John Wiley & Sons, Inc.
42. Gahlawat, G., & Choudhury, A. R., (2019). A review on the biosynthesis of metal and metal salt nanoparticles by microbes. *RSC Advances, 9*(23), 12944–12967.
43. Ganaie, A. H., Ghasura, R. S., Mir, N. A., Bumla, N. A., Sankar, G., & Wani, S. A., (2013). Biochemical and physiological changes during thermal stress in bovines: A review. *Iranian Journal of Applied Animal Science, 3*(3), 423–430.
44. Ganaie, S. U., Abbasi, T., & Abbasi, S. A., (2016). Low-cost, environment-friendly synthesis of palladium nanoparticles by utilizing a terrestrial weed *Antigonon leptopus*. *Particulate Science and Technology, 34*(2), 201–208.
45. Ganaie, S. U., Abbasi, T., & Abbasi, S. A., (2016). Rapid and green synthesis of bimetallic Au–Ag nanoparticles using an otherwise worthless weed *Antigonon leptopus*. *Journal of Experimental Nanoscience, 11*(6), 395–417.
46. Ganguly, S., & Mukhopadhayay, S. K., (2011). Nano-science and nanotechnology: Journey from past to present and prospect in veterinary science and medicine. *International Journal of Nanoscience and Nanotechnology, 2*(1), 79–83.
47. Gebler, M., Uiterkamp, A. J. S., & Visser, C., (2014). A global sustainability perspective on 3D printing technologies. *Energy Policy, 74*, 158–167.
48. Gericke, M., & Pinches, A., (2006). Microbial production of gold nanoparticles. *Gold Bulletin, 39*(1), 22–28.
49. Giese, B., Klaessig, F., Park, B., Kaegi, R., Steinfeldt, M., Wigger, H., Von, G. A., & Gottschalk, F., (2018). Risks, release, and concentrations of engineered nanomaterial in the environment. *Scientific Reports, 8*(1), 1–18.
50. Gogoi, S. K., Gopinath, P., Paul, A., Ramesh, A., Ghosh, S. S., & Chattopadhyay, A., (2006). Green fluorescent protein-expressing *Escherichia coli* as a model system for investigating the antimicrobial activities of silver nanoparticles. *Langmuir: The ACS Journal of Surfaces and Colloids, 22*(22), 9322–9328.
51. Gokarneshan, N., & Velumani, K., (2017). Application of nano-silver particles on textile materials for improvement of antibacterial finishes. *Global Journal of Nanomedicine, 2*(2), 555586. https://doi.org/10.19080/GJN.2017.02.555586.
52. Granados, A., Pleixats, R., & Vallribera, A., (2021). Recent advances on antimicrobial and anti-inflammatory cotton fabrics containing nanostructures. *Molecules, 26*(10), 3008. https://doi.org/10.3390/molecules26103008.
53. Grigore, M. E., Biscu, E. R., Holban, A. M., Gestal, M. C., & Grumezescu, A. M., (2016). Methods of synthesis, properties, and biomedical applications of CuO nanoparticles. *Pharmaceuticals, 9*(4), 75. https://doi.org/10.3390/ph9040075.

54. Hamida, R. S., Abdelmeguid, N. E., Ali, M. A., Bin-Meferij, M. M., & Khalil, M. I., (2020). Synthesis of silver nanoparticles using a novel cyanobacteria *Desertifilum sp*. extract: Their antibacterial and cytotoxicity effects. *International Journal of Nanomedicine, 15*, 49–63.
55. Heath, J. R., (2015). Nanotechnologies for biomedical science and translational medicine. *Proceedings of the National Academy of Sciences, 112*(47), 14436–14443.
56. Hildebrand, H., Mackenzie, K., & Kopinke, F. D., (2009). Pd/Fe_3O_4 nano-catalysts for selective dehalogenation in wastewater treatment processes-Influence of water constituents. *Applied Catalysis B: Environmental, 91*(1, 2), 389–396.
57. Hou, M. J., & Shah, D. O., (1988). Formation and characterization of ultrafine silver halide particle. In: Attia, Y. A., Moudgil, B. M., & Chandler, S., (eds.), *Interfacial Phenomena in Biotechnology and Materials Processing* (pp. 443–458). Amsterdam: Elsevier.
58. Hu, A., Yao, Z., & Yu, X., (2009). Phase behavior of a sodium dodecanol allyl sulfosuccinic diester/n-pentanol/methyl acrylate/butyl acrylate/water microemulsion system and preparation of acrylate latexes by microemulsion polymerization. *Journal of Applied Polymer Science, 113*(4), 2202–2208.
59. Hulla, J. E., Sahu, S. C., & Hayes, A. W., (2015). Nanotechnology: History and future. *Human & Experimental Toxicology, 34*(12), 1318–1321.
60. Hunault, M. O., Loisel, C., Bauchau, F., Lemasson, Q., Pacheco, C., Pichon, L., Moignard, B., et al., (2017). Nondestructive redox quantification reveals glassmaking of rare French gothic stained glasses. *Analytical Chemistry, 89*(11), 6277–6284.
61. Ibrahim, N. K., & Al Farttoosi, H. A. K., (2019). Response of mung bean to boron nanoparticles and spraying stages (*Vigna Radiata* L.). *Plant Archives, 19*, 712–715.
62. Ijaz, I., Gilani, E., Nazir, A., & Bukhari, A., (2020). Detail review on chemical, physical, and green synthesis, classification, characterizations, and applications of nanoparticles. *Green Chemistry Letters and Reviews, 13*(3), 223–245.
63. Ingle, A. P., & Rai, M., (2017). Copper nanoflowers as effective antifungal agents for plant pathogenic fungi. *IET Nanobiotechnology, 11*(5), 546–551.
64. Intarasawang, M., & Thamaphat, K., (2013). Utilization of aquatic weed for environmental and rapid synthesis of silver nanoparticles. In: Jiang, Z. Y., & Kim, Y. H., (eds.), *Advanced Materials Research* (pp. 80–83). Switzerland: Trans Tech Publications Ltd.
65. Iravani, A., Akbari, M. H., & Zohoori, M., (2017). Advantages and disadvantages of green technology; goals, challenges, and strengths. *International Journal of Science and Engineering Applications, 6*(9), 272–284.
66. Jahan, N., Aslam, S., Rahman, K. U., Fazal, T., Anwar, F., & Saher, R., (2016). Formulation and characterization of nanosuspension of herbal extracts for enhanced antiradical potential. *Journal of Experimental Nanoscience, 11*(1), 72–80.
67. Jakhmola, A., Vecchione, R., Onesto, V., Gentile, F., Celentano, M., & Netti, P. A., (2021). Experimental and theoretical studies on sustainable synthesis of gold sol displaying dichroic effect. *Nanomaterials, 11*(1), 236. https://doi.org/10.3390/nano11010236.
68. Jameel, M., Shoeb, M., Khan, M. T., Ullah, R., Mobin, M., Farooqi, M. K., & Adnan, S. M., (2020). Enhanced insecticidal activity of thiamethoxam by zinc oxide nanoparticles: A novel nanotechnology approach for pest control. *ACS Omega, 5*(3), 1607–1615.
69. Jebril, S., Jenana, R. K. B., & Dridi, C., (2020). Green synthesis of silver nanoparticles using *Melia azedarach* leaf extract and their antifungal activities: *In vitro* and *in vivo*. *Materials Chemistry and Physics, 248*, 122898. https://doi.org/10.1016/j.matchemphys.2020.12289.

70. Kar, S., & Tewari, P. K., (2013). Nanotechnology for domestic water purification. In: Pacheco-Torgal, F., Diamanti, M. V., Nazari, A., & Goran-Granqvist, C., (eds.), *Nanotechnology in Eco-Efficient Construction* (pp. 364–427). Woodhead Publishing.
71. Karn, B., & Wong, S. S., (2013). Ten years of green nanotechnology. In: Shamim, N., & Sharma, V. K., (eds.), *Sustainable Nanotechnology and the Environment: Advances and Achievements* (pp. 1–10). American Chemical Society Publications.
72. Karny, A., Zinger, A., Kajal, A., Shainsky-Roitman, J., & Schroeder, A., (2018). Therapeutic nanoparticles penetrate leaves and deliver nutrients to agricultural crops. *Scientific Reports, 8*(1), 1–10.
73. Kaul, S., Gulati, N., Verma, D., Mukherjee, S., & Nagaich, U., (2018). Role of nanotechnology in cosmeceuticals: A review of recent advances. *Journal of Pharmaceutics, 2018*, 1–20.
74. Kaushal, M., & Wani, S. P., (2017). Nanosensors: Frontiers in precision agriculture. In: Prasad, R., Kumar, M., & Kumar, V., (eds.), *Nanotechnology* (pp. 279–291). Singapore: Springer.
75. Klaine, S. J., Alvarez, P. J., Batley, G. E., Fernandes, T. F., Handy, R. D., Lyon, D. Y., Mahendra, S., et al., (2008). Nanomaterials in the environment: Behavior, fate, bioavailability, and effects. *Environmental Toxicology and Chemistry, 27*(9), 1825–1851.
76. Kleppner, D., (1999). A short history of atomic physics in the 20th century. *Reviews of Modern Physics, 71*(2), 78–84.
77. Kool, L., Dekker, F., Bunschoten, A., Smales, G. J., Pauw, B. R., Velders, A. H., & Saggiomo, V., (2020). Gold and silver dichroic nanocomposite in the quest for 3D printing the Lycurgus cup. *Beilstein Journal of Nanotechnology, 11*(1), 16–23.
78. Kostarelos, K., Lacerda, L., Pastorin, G., Wu, W., Wieckowski, S., Luangsivilay, J., Sylvie, G., S., et al., (2007). Cellular uptake of functionalized carbon nanotubes is independent of functional group and cell type. *Nature Nanotechnology, 2*(2), 108–113.
79. Koumoulos, E. P., Gkartzou, E., & Charitidis, C. A., (2017). Additive (nano) manufacturing perspectives: The use of nanofillers and tailored materials. *Manufacturing Review, 4*(12), 1–9.
80. Krantzberg, G., Tanik, A., Do Carmo, J. S. A., Indarto, A., Ekdal, A., Gurel, M., Pehlivanoglu M. E., Wang, Z., Wang, G., Zhao, C., & Machiwal, D., (2010). *Advances in Water Quality Control* (pp. 1–311). USA: Scientific Research Publishing, Inc.
81. LaMer, V. K., & Dinegar, R. H., (1950). Theory, production, and mechanism of formation of monodispersed hydrosols. *Journal of the American Chemical Society, 72*(11), 4847–4854.
82. Lai, X., Zhao, H., Zhang, Y., Guo, K., Xu, Y., Chen, S., & Zhang, J., (2018). Intranasal delivery of copper oxide nanoparticles induces pulmonary toxicity and fibrosis in C57BL/6 mice. *Scientific Reports, 8*(1), 1–12.
83. Lal, M., Chhabra, V., Ayyub, P., & Maitra, A., (1998). Preparation and characterization of ultrafine TiO_2 particles in reverse micelles by hydrolysis of titanium di-ethylhexyl sulfosuccinate. *Journal of Materials Research, 13*(5), 1249–1254.
84. Lammers, T., Aime, S., Hennink, W. E., Storm, G., & Kiessling, F., (2011). Theranostic nanomedicine. *Accounts of Chemical Research, 44*(10), 1029–1038.
85. Lapworth, D. J., Baran, N., Stuart, M. E., & Ward, R. S., (2012). Emerging organic contaminants in groundwater: A review of sources, fate, and occurrence. *Environmental Pollution, 163*, 287–303.
86. Letfullin, R. R., & George, T. F., (2016). Introduction to nanomedicine. In: *Computational Nanomedicine and Nanotechnology* (pp. 1–61). Springer.

87. Lin, Y. H., Lin, J. H., Chou, S. C., Chang, S. J., Chung, C. C., Chen, Y. S., & Chang, C. H., (2015). Berberine-loaded targeted nanoparticles as specific Helicobacter pylori eradication therapy: *In vitro* and *in vivo* study. *Nanomedicine, 10*(1), 57–71.
88. Liu, Y., Tong, Z., & Prud'homme, R. K., (2008). Stabilized polymeric nanoparticles for controlled and efficient release of bifenthrin. *Pest Management Science: Formerly Pesticide Science, 64*(8), 808–812.
89. Lok, C. N., Ho, C. M., Chen, R., He, Q. Y., Yu, W. Y., Sun, H., Tam, P. K., et al., (2006). Proteomic analysis of the mode of antibacterial action of silver nanoparticles. *Journal of Proteome Research, 5*(4), 916–924.
90. Losic, D., Yu, Y., Aw, M. S., Simovic, S., Thierry, B., & Addai-Mensah, J., (2010). Surface functionalization of diatoms with dopamine modified iron-oxide nanoparticles: Toward magnetically guided drug microcarriers with biologically derived morphologies. *Chemical Communications, 46*(34), 6323–6325.
91. Lu, Y., & Ozcan, S., (2015). Green nanomaterials: On track for a sustainable future. *Nano-Today, 10*(4), 417–420.
92. Lyu, S., Wei, X., Chen, J., Wang, C., Wang, X., & Pan, D., (2017). Titanium as a beneficial element for crop production. *Frontiers in Plant Science, 8*, 597. https://doi.org/10.3389/fpls.2017.00597.
93. Maksimović, M., (2017). The roles of nanotechnology and internet of nano-things in healthcare transformation. *TecnoLógicas, 20*(40), 139–153.
94. Malik, A., Chaudhary, S., Garg, G., & Tomar, A., (2012). Dendrimers: A tool for drug delivery. *International Journal of Advanced Biological and Biomedical Research, 6*(4), 165–169.
95. Mansoori, G. A., & Soelaiman, T. F., (2005). Nanotechnology-an introduction for the standards community. *Journal of ASTM International, 2*(6), 1–22.
96. Metcalf, L., Eddy, H. P., & Tchobanoglous, G., (1979). *Wastewater Engineering: Treatment Disposal Reuse* (2nd edn., p. 920). New York: McGraw-Hill.
97. Meulebroeck, W., Wouters, H., Nys, K., & Thienpont, H., (2016). Authenticity screening of stained glass windows using optical spectroscopy. *Scientific Reports, 6*(1), 1–10.
98. Mirzajani, F., Askari, H., Hamzelou, S., Schober, Y., Römpp, A., Ghassempour, A., & Spengler, B., (2014). Proteomics study of silver nanoparticles toxicity on *Oryza sativa* L. *Ecotoxicology and Environmental Safety, 108*, 335–339.
99. Mishra, M., Arukha, A. P., Bashir, T., Yadav, D., & Prasad, G. B. K. S., (2017). All new faces of diatoms: Potential source of nanomaterials and beyond. *Frontiers in Microbiology, 8*, 1239. https://doi.org/10.3389/fmicb.2017.01239.
100. Mishra, S. B., Pandey, H., & Pandey, A. C., (2013). Nanosuspension of *Phyllanthus amarus* extract for improving oral bioavailability and prevention of paracetamol induced hepatotoxicity in Sprague–Dawley rats. *Advances in Natural Sciences: Nanoscience and Nanotechnology, 4*, 035007. https://doi.org/10.1088/2043-6262/4/3/035007.
101. Mitin, V., Sementsov, D., & Vagidov, N., (2010). The nanoworld and quantum physics. In: Mitin, V., Sementsov, D., & Vagidov, N., (eds.), *Quantum Mechanics for Nanostructures* (pp. 1–18). Cambridge: Cambridge University Press.
102. Mochochoko, T., Oluwafemi, O. S., Jumbam, D. N., & Songca, S. P., (2013). Green synthesis of silver nanoparticles using cellulose extracted from an aquatic weed; water hyacinth. *Carbohydrate Polymers, 98*(1), 290–294.
103. Morones, J. R., Elechiguerra, J. L., Camacho, A., Holt, K., Kouri, J. B., Ramírez, J. T., & Yacaman, M. J., (2005). The bactericidal effect of silver nanoparticles. *Nanotechnology, 16*(10), 2346–2353.

104. Mousa, S. A., & Bharali, D. J., (2011). Nanotechnology-based detection and targeted therapy in cancer: Nano-bio paradigms and applications. *Cancers, 3*(3), 2888–2903.
105. Mu, Q., Broughton, D. L., & Yan, B., (2009). Endosomal leakage and nuclear translocation of multiwalled carbon nanotubes: Developing a model for cell uptake. *Nano-Letters, 9*(12), 4370–4375.
106. MubarakAli, D., Arunkumar, J., Nag, K. H., SheikSyedIshack, K. A., Baldev, E., Pandiaraj, D., & Thajuddin, N., (2013). Gold nanoparticles from pro and eukaryotic photosynthetic microorganisms-Comparative studies on synthesis and its application on biolabeling. *Colloids and Surfaces B: Biointerfaces, 103*, 166–173.
107. Mueller, N. C., & Nowack, B., (2010). Nanoparticles for remediation: Solving big problems with little particles. *Elements, 6*, 395–400.
108. Mukherjee, A., Majumdar, S., Servin, A. D., Pagano, L., Dhankher, O. P., & White, J. C., (2016). Carbon nanomaterials in agriculture: A critical review. *Frontiers in Plant Science, 7*, 172. https://doi.org/10.3389/fpls.2016.00172.
109. Müller, R. H., Petersen, R. D., Hommoss, A., & Pardeike, J., (2007). Nanostructured lipid carriers (NLC) in cosmetic dermal products. *Advanced Drug Delivery Reviews, 59*(6), 522–530.
110. Murphy, M., Ting, K., Zhang, X., Soo, C., & Zheng, Z., (2015). Current development of silver nanoparticle preparation, investigation, and application in the field of medicine. *Journal of Nanomaterials, 2015*, 1–12.
111. Nadagouda, M. N., Speth, T. F., & Varma, R. S., (2011). Microwave-assisted green synthesis of silver nanostructures. *Accounts of Chemical Research, 44*(7), 469–478.
112. Nath, D., & Banerjee, P., (2013). Green nanotechnology: A new hope for medical biology. *Environmental Toxicology and Pharmacology, 36*(3), 997–1014.
113. Nazir, R., Ayub, Y., & Tahir, L., (2020). Green-nanotechnology for precision and sustainable agriculture. In: Ghorbanpour, M., Bhargava, P., Varma, A., & Choudhary, D., (eds.), *Biogenic Nano-Particles and Their use in Agro-Ecosystems* (pp. 317–357). Singapore: Springer.
114. Nowack, B., (2008). Pollution prevention and treatment using nanotechnology. In: Krug, H., (eds.), *Nanotechnology Environmental Aspects* (pp. 1–15).Wiley-VCH Verlag GmbH & Co. KGaA: Weinheim.
115. O'Carroll, D., Sleep, B., Krol, M., Boparai, H., & Kocur, C., (2013). Nanoscale zero-valent iron and bimetallic particles for contaminated site remediation. *Advances in Water Resources, 51*, 104–122.
116. Omanović-Mikličanin, E., Maksimović, M., & Vujović, V., (2015). The future of healthcare: Nanomedicine and internet of nano-things. *Folia Medica Facultatis Medicinae Universitatis Saraeviensis, 50*(1), 23–28.
117. Padalia, H., & Chanda, S., (2017). Characterization, antifungal, and cytotoxic evaluation of green synthesized zinc oxide nanoparticles using *Ziziphus nummularia* leaf extract. *Artificial Cells, Nanomedicine, and Biotechnology, 45*(8), 1751–1761.
118. Padeletti, G., & Fermo, P., (2004). Production of gold and ruby-red lustres in Gubbio (Umbria, Italy) during the renaissance period. *Applied Physics A, 79*(2), 241–245.
119. Pandey, G., (2018). Challenges and future prospects of agri-nanotechnology for sustainable agriculture in India. *Environmental Technology & Innovation, 11*, 299–307.
120. Pardeike, J., Hommoss, A., & Müller, R. H., (2009). Lipid nanoparticles (SLN, NLC) in cosmetic and pharmaceutical dermal products. *International Journal of Pharmaceutics, 366*(1, 2), 170–184.

121. Pedone, D., Moglianetti, M., De Luca, E., Bardi, G., & Pompa, P. P., (2017). Platinum nanoparticles in nanobiomedicine. *Chemical Society Reviews, 46*(16), 4951–4975.
122. Pileni, M. P., (2003). The role of soft colloidal templates in controlling the size and shape of inorganic nanocrystals. *Nature Materials, 2*(3), 145–150.
123. Pirtarighat, S., Ghannadnia, M., & Baghshahi, S., (2019). Green synthesis of silver nanoparticles using the plant extract of *Salvia spinosa* grown *in vitro* and their antibacterial activity assessment. *Journal of Nanostructure in Chemistry, 9*(1), 1–9.
124. Porkodi, G., & Anand, G., (2020). Nanotechnology and its application in water treatment: A review. *International Journal of Environmental & Agriculture Research, 6*(2), 59–66.
125. Prasad, R., (2014). Synthesis of silver nanoparticles in photosynthetic plants. *Journal of Nanoparticles, 2014*, 1–8.
126. Prasad, R., Bhattacharyya, A., & Nguyen, Q. D., (2017). Nanotechnology in sustainable agriculture: Recent developments, challenges, and perspectives. *Frontiers in Microbiology, 8*(1014), 1–13.
127. Rahimpour, Y., & Hamishehkar, H., (2012). Liposomes in cosmeceutics. *Expert Opinion on Drug Delivery, 9*(4), 443–455.
128. Rahman, M., & Rebrov, E. V., (2014). Microreactors for gold nanoparticles synthesis: From faraday to flow. *Processes, 2*(2), 466–493.
129. Ramesh, A., Sundari, M. T., & Thirugnanam, P. E., (2015). Microbial molecular mechanisms in biosynthesis of nanoparticles. In: Singh, O. V., (eds.), *Bio-nanoparticles: Biosynthesis and Sustainable Biotechnological Implications* (pp. 53–81). Wiley-Blackwell.
130. Rastogi, A., Tripathi, D. K., Yadav, S., Chauhan, D. K., Živčák, M., Ghorbanpour, M., El-Sheery, N. I., & Brestic, M., (2019). Application of silicon nanoparticles in agriculture. *3 Biotech, 9*(3), 1–11.
131. Razo, S. C., Panferova, N. A., Panferov, V. G., Safenkova, I. V., Drenova, N. V., Varitsev, Y. A., Zherdev, A. V., et al., (2019). Enlargement of gold nanoparticles for sensitive immunochromatographic diagnostics of potato brown rot. *Sensors (Basel, Switzerland)*, *19*(1), 1–16.
132. Razzacki, S. Z., Thwar, P. K., Yang, M., Ugaz, V. M., & Burns, M. A., (2004). Integrated microsystems for controlled drug delivery. *Advanced Drug Delivery Reviews, 56*(2), 185–198.
133. Reynolds, E. A., (2013). The development of stained glass in gothic cathedrals. *JCCC Honors Journal, 4*(1), 3. http://scholarspace.jccc.edu/honors_journal/vol4/iss1/3.
134. Rizzo, L. Y., Theek, B., Storm, G., Kiessling, F., & Lammers, T., (2013). Recent progress in nanomedicine: Therapeutic, diagnostic, and theranostic applications. *Current Opinion in Biotechnology, 24*(6), 1159–1166.
135. Roco, M. C., (2011). The long view of nanotechnology development: The national nanotechnology initiative at 10 years. In: *Nanotechnology Research Directions for Societal Needs in 2020* (pp. 1–28). Dordrecht-Netherlands: Springer.
136. Roco, M. C., (2003). Nanotechnology: Convergence with modern biology and medicine. *Current Opinion in Biotechnology, 14*(3), 337–346.
137. Roychoudhury, P., Gopal, P. K., Paul, S., & Pal, R., (2016). Cyanobacteria assisted biosynthesis of silver nanoparticles-a potential antileukemic agent. *Journal of Applied Phycology, 28*(6), 3387–3394.
138. Saini, R., Saini, S., & Sharma, S., (2010). Nanotechnology: The future medicine. *Journal of Cutaneous and Aesthetic Surgery, 3*(1), 32, 33.

139. Sanzari, I., Leone, A., & Ambrosone, A., (2019). Nanotechnology in plant science: To make a long story short. *Frontiers in Bioengineering and Biotechnology, 7*, 1–12.
140. Savi, M., Bocchi, L., Cacciani, F., Vilella, R., Buschini, A., Perotti, A., Galati, S., et al., (2021). Cobalt oxide nanoparticles induce oxidative stress and alter electromechanical function in rat ventricular myocytes. *Particle and Fiber Toxicology, 18*(1), 1. https://doi.org/10.1186/s12989-020-00396-6.
141. Schraufnagel, D. E., (2020). The health effects of ultrafine particles. *Experimental & Molecular Medicine, 52*(3), 311–317.
142. Sciau, P., & Goudeau, P., (2015). Ceramics in art and archaeology: A review of the materials science aspects. *The European Physical Journal B, 88*(5), 1–11.
143. Seleiman, M. F., Almutairi, K. F., Alotaibi, M., Shami, A., Alhammad, B. A., & Battaglia, M. L., (2021). Nano-fertilization as an emerging fertilization technique: Why can modern agriculture benefit from its use?. *Plants, 10*(1), 1–27.
144. Shah, M., Badwaik, V., Kherde, Y., Waghwani, H. K., Modi, T., Aguilar, Z. P., Rodgers, H., et al., (2014). Gold nanoparticles: Various methods of synthesis and antibacterial applications. *Frontiers in bioscience (Landmark edition), 19*, 1320–1344.
145. Shakhverdova, I. P., Reibold, M., Kochmann, W., & Paufler, P., (2016). Nanoscratching meets nanoindentation. *Zeitschrift für Kristallographie-Crystalline Materials, 231*(6), 351–363.
146. Shang, Y., Hasan, M. K., Ahammed, G. J., Li, M., Yin, H., & Zhou, J., (2019). Applications of nanotechnology in plant growth and crop protection: A review. *Molecules (Basel, Switzerland)*, *24*(14), 1–23.
147. Shao, F., Yang, A., Yu, D. M., Wang, J., Gong, X., & Tian, H. X., (2018). Bio-synthesis of *Barleria gibsoni* leaf extract mediated zinc oxide nanoparticles and their formulation gel for wound therapy in nursing care of infants and children. *Journal of Photochemistry and Photobiology B, Biology, 189*, 267–273.
148. Sharma, P., Sharma, A., Sharma, M., Bhalla, N., Estrela, P., Jain, A., Thakur, P., & Thakur, A., (2017). Nanomaterial fungicides: *In vitro* and *in vivo* antimycotic activity of cobalt and nickel nanoferrites on phytopathogenic fungi. *Global Challenges (Hoboken, NJ), 1*(9), 1700041. https://doi.org/10.1002/gch2.201700041.
149. Shen, M. H., Zhou, X. X., Yang, X. Y., Chao, J. B., Liu, R., & Liu, J. F., (2015). Exposure medium: Key in identifying free Ag^+ as the exclusive species of silver nanoparticles with acute toxicity to *Daphnia magna*. *Scientific Reports, 5*, 1–8.
150. Shidhaye, S. S., Vaidya, R., Sutar, S., Patwardhan, A., & Kadam, V. J., (2008). Solid lipid nanoparticles and nanostructured lipid carriers-innovative generations of solid lipid carriers. *Current Drug Delivery, 5*(4), 324–331.
151. Shinde, S., Paralikar, P., Ingle, A. P., & Rai, M., (2020). Promotion of seed germination and seedling growth of *Zea mays* by magnesium hydroxide nanoparticles synthesized by the filtrate from *Aspergillus niger*. *Arabian Journal of Chemistry, 13*(1), 3172–3182.
152. Shong, C. W., Sow, C. H., & Wee, A. T., (2010). *Science at the Nanoscale: An Introductory Textbook* (pp. 228). Singapore: Pan Stanford Publishing.
153. Silva, G. A., (2004). Introduction to nanotechnology and its applications to medicine. *Surgical Neurology, 61*(3), 216–220.
154. Singh, G., Babele, P. K., Shahi, S. K., Sinha, R. P., Tyagi, M. B., & Kumar, A., (2014). Green synthesis of silver nanoparticles using cell extracts of *Anabaena doliolum* and screening of its antibacterial and antitumor activity. *Journal of Microbiology and Biotechnology, 24*(10), 1354–1367.

155. Singh, P., Kim, Y. J., Zhang, D., & Yang, D. C., (2016). Biological synthesis of nanoparticles from plants and microorganisms. *Trends in Biotechnology, 34*(7), 588–599.
156. Slepička, P., Slepičková, K. N., Siegel, J., Kolská, Z., & Švorčík, V., (2020). Methods of gold and silver nanoparticles preparation. *Materials, 13*(1), 1–22.
157. Smijs, T. G., & Pavel, S., (2011). Titanium dioxide and zinc oxide nanoparticles in sunscreens: Focus on their safety and effectiveness. *Nanotechnology, Science, and Applications, 4*, 95–112.
158. Sohrt, J., Lang, F., & Weiler, M., (2017). Quantifying components of the phosphorus cycle in temperate forests. *Wiley Interdisciplinary Reviews: Water, 4*(6), 1–36.
159. Srivastava, S. K., & Constanti, M., (2012). Room temperature biogenic synthesis of multiple nanoparticles (Ag, Pd, Fe, Rh, Ni, Ru, Pt, Co, and Li) by *Pseudomonas aeruginosa* SM1. *Journal of Nanoparticle Research, 14*(4), 1–10.
160. Steffy, K., Shanthi, G., Maroky, A. S., & Selvakumar, S., (2018). Potential bactericidal activity of S. nux-vomica–ZnO nanocomposite against multidrug-resistant bacterial pathogens and wound-healing properties. *Journal of Trace Elements in Medicine and Biology, 50*, 229–239.
161. Stoimenov, P. K., Klinger, R. L., Marchin, G. L., & Klabunde, K. J., (2002). Metal oxide nanoparticles as bactericidal agents. *Langmuir, 18*(17), 6679–6686.
162. Sui, Z., Meng, Q., Zhang, X., Ma, R., & Cao, B., (2012). Green synthesis of carbon nanotube–graphene hybrid aerogels and their use as versatile agents for water purification. *Journal of Materials Chemistry, 22*(18), 8767–8771.
163. Sun, T., Zhang, Z., Xiao, J., Chen, C., Xiao, F., Wang, S., & Liu, Y., (2013). Facile and green synthesis of palladium nanoparticles-graphene-carbon nanotube material with high catalytic activity. *Scientific Reports, 3*(1), 1–6.
164. Taghavi, S. M., Momenpour, M., Azarian, M., Ahmadian, M., Souri, F., Taghavi, S. A., Sadeghain, M., & Karchani, M., (2013). Effects of Nanoparticles on the Environment and Outdoor Workplaces. *Electronic Physician, 5*(4), 706–712.
165. Taherian, M., Bostani, A., & Omidi, H., (2019). Boron and pigment content in alfalfa affected by nano-fertilization under calcareous conditions. *Journal of Trace Elements in Medicine and Biology: Organ of the Society for Minerals and Trace Elements (GMS), 53*, 136–143.
166. Terracciano, M., Shahbazi, M. A., Correia, A., Rea, I., Lamberti, A., De Stefano, L., & Santos, H. A., (2015). Surface bioengineering of diatomite based nanovectors for efficient intracellular uptake and drug delivery. *Nanoscale, 7*(47), 20063–20074.
167. Thombre, R., Chitnis, A., Kadam, V., Bogawat, Y., Colaco, R., & Kale, A. A., (2014). Facile method for synthesis of biostabilized silver nanoparticles using *Eichhornia crassipes* (Mart.) solms (water hyacinth). *Indian Journal of Biotechnology, 13*(3), 337–341.
168. Tiwari, D. K., Behari, J., & Sen, P., (2008). Application of nanoparticles in wastewater treatment. *World Applied Sciences Journal, 3*(3), 417–433.
169. Tripathi, N., Pavelyev, V., & Islam, S. S., (2017). Synthesis of carbon nanotubes using green plant extract as catalyst: Unconventional concept and its realization. *Applied Nanoscience, 7*(8), 557–566.
170. Tyagi, S., Rawtani, D., Khatri, N., & Tharmavaram, M., (2018). Strategies for nitrate removal from aqueous environment using nanotechnology: A review. *Journal of Water Process Engineering, 21*, 84–95.
171. U.S. Environmental Protection Agency (EPA), (2007). Nanotechnology White Paper (pp. 137). https://archive.epa.gov/osa/pdfs/web/pdf/epa-nanotechnology-whitepaper-0207.pdf (accessed on 9 July 2022).

172. Velu, R., Calais, T., Jayakumar, A., & Raspall, F., (2020). A comprehensive review on bio-nanomaterials for medical implants and feasibility studies on fabrication of such implants by additive manufacturing technique. *Materials, 13*(1), 92. https://doi.org/10.3390/ma13010092.
173. Verma, A., Gautam, S. P., Bansal, K. K., Prabhakar, N., & Rosenholm, J. M., (2019). Green nanotechnology: Advancement in phytoformulation research. *Medicines (Basel, Switzerland), 6*(1), 39. https://doi.org/10.3390/medicines6010039.
174. Vijayakumar, S., Vaseeharan, B., Malaikozhundan, B., & Shobiya, M., (2016). *Laurus nobilis* leaf extract mediated green synthesis of ZnO nanoparticles: Characterization and biomedical applications. *Biomedicine & pharmacotherapy. Biomedecine & Pharmacotherapie, 84*, 1213–1222.
175. Vinayan, B. P., Nagar, R., & Ramaprabhu, S., (2013). Solar light assisted green synthesis of palladium nanoparticle decorated nitrogen-doped graphene for hydrogen storage application. *Journal of Materials Chemistry A, 1*(37), 11192–11199.
176. Wakaskar, R. R., (2018). General overview of lipid-polymer hybrid nanoparticles, dendrimers, micelles, liposomes, spongosomes, and cubosomes. *Journal of Drug Targeting, 26*(4), 311–318.
177. War, J. M., Fazili, M. A., Mushtaq, W., Wani, A. H., & Bhat, M. Y., (2020). Role of nanotechnology in crop improvement. In: Hakeem, K., & Pirzadah, T., (eds.), *Nanobiotechnology in Agriculture: Nanotechnology in the Life Sciences*. (pp. 63–97). Springer.
178. Worrall, E. A., Hamid, A., Mody, K. T., Mitter, N., & Pappu, H. R., (2018). Nanotechnology for plant disease management. *Agronomy, 8*(12), 1–24.
179. Xia, L., Lenaghan, S. C., Zhang, M., Zhang, Z., & Li, Q., (2010). Naturally occurring nanoparticles from English ivy: An alternative to metal-based nanoparticles for UV protection. *Journal of Nanobiotechnology, 8*(1), 1–9.
180. Xie, J., Lee, S., & Chen, X., (2010). Nanoparticle-based theranostic agents. *Advanced Drug Delivery Reviews, 62*(11), 1064–1079.
181. Yadav, I. C., Devi, N. L., Syed, J. H., Cheng, Z., Li, J., Zhang, G., & Jones, K. C., (2015). Current status of persistent organic pesticides residues in air, water, and soil, and their possible effect on neighboring countries: A comprehensive review of India. *Science of the Total Environment, 511*, 123–137.
182. Yunus, I. S., Harwin, Kurniawan, A., Adityawarman, D., & Indarto, A., (2012). Nanotechnologies in water and air pollution treatment. *Environmental Technology Reviews, 1*(1), 136–148.
183. Zhang, D., Qi, L., Ma, J., & Cheng, H., (2002). Formation of crystalline nanosized titania in reverse micelles at room temperature. *Journal of Materials Chemistry, 12*(12), 3677–3680.
184. Zheng, Y., Wang, Z., Peng, F., & Fu, L., (2016). Application of biosynthesized ZnO nanoparticles on an electrochemical H_2O_2 biosensor. *Brazilian Journal of Pharmaceutical Sciences, 52*, 781–786.