REVIEW ARTICLE

Progressive Biofunctional Nanoplatforms for Treatment of vital Non-Communicable Diseases: A critical review

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Abstract:
Noncommunicable diseases (NCDs), together with cancer, cardiovascular illnesses, diabetes, and chronic respiratory diseases, continue to be the biggest contributors to morbidity and mortality worldwide. The drawbacks of conventional medicines, such as low bioavailability, systemic toxicity, and ineffective targeted administration, have paved the path for the blooming of bioactive nanomaterials. Nanomaterials are now broadly utilized in the medical and health industries as an innovative treatment for various diseases, primarily NCDs, caused by rapid advancements in nanotechnology. These advanced materials offer distinct advantages, including precise targeting, controlled dispensing, and enhanced therapeutic efficacy. Bioactive nanomaterials (BNMs) use chemical and mechanical characteristics such as crystal structure, charge on the surface, functional groups on the surface, arrangement, and size to generate biological activity and treat illnesses. Unlike traditional nanometer pharmaceutical composing, BNMs do not rely on drug delivery and are anticipated to offer improved therapeutic outcomes. This study reviews the recent advancements, mechanisms, a thorough introduction to the usual biomedical applications involving bioactive nanoparticles and therapeutic prospects of futuristic bioactive nanoparticles in the treatment of major NCDs, as well as the accompanying challenges, technical hurdles and significant scientific issues confronting bioactive nanoparticles in disease diagnosis and therapy and forthcoming developments.

Keywords: Non-communicable diseases (NCDs); Nanomaterials; Bioactivity; Inorganic nanomaterials; Organic nanomaterials; Treatment; Bioavailability

How to cite this article: Dutta T, Hazarika S, Baruah S, Phangchopi N, Phukan S, Lahkar L, Chetia J, Dutta MP, Saikia M. Progressive Biofunctional Nanoplatforms for Treatment of Vital Non-Communicable Diseases: A Critical Review. Int J Drug Deliv Technol. 2026;16(20s): 759-775. DOI: 10.25258/ijddt.16.20s.76

1. Introduction:

The term NCDs refers to a set of illnesses that are not primarily caused by an acute infection, but have long-term health implications and frequently necessitate long-term therapy and care. Cancer, cardiovascular disease, diabetes, and chronic lung ailments are examples of such conditions. Chronic NCDs, also referred to as chronic diseases, are long-term conditions that often progress gradually. Over the last few decades, there has been a dramatic increase in chronic NCDs among people of all ages, making it one of the major causes of death worldwide [1]. These NCDs are persistent and non-transferable health disorders that are intimately associated with an individual's lifestyle and exposure to environmental toxins, with many resulting from poor diets and harmful behavioural patterns such as tobacco and alcohol use [2]. Both communicable and noncommunicable diseases pose serious risks to global public health. Treatment of many diseases/disorders frequently relies on the efficient delivery of therapeutic agents, especially when working with medications with low water solubility.

The term nanomaterials refer to nanoscale structural materials, which refer to solid materials with nanoparticles no larger than 100 nm, they refer to all kinds of solid ultra-fine materials with at least one dimension of the three-dimensional spatial scale of microstructure [3]. Currently, nanotechnology encompasses nanoelectronics, nanomechanics, nanomaterials science, nanochemistry, nanobiology, and other areas. Nanoparticles are increasingly recognized for their potential to revolutionize the treatment and management of chronic diseases, which pose significant global health challenges due to their complex etiology and the limitations of conventional therapies. Despite substantial advances in our understanding of the human body at the molecular and nanoscale levels, progress in developing effective diagnostic and therapeutic tools for diagnosing chronic diseases has lagged [11,12].

1.1 NCD disease as a global threat:

NCDs are on the rise in low- and middle-income countries, where 87% of premature deaths occur. The World Health Organization evaluates that 40 million

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people die each year from NCDs, accounting for 70% of all global deaths, and 17 million die before the age of 70. Cardiovascular diseases (CVDs), cancer, respiratory disorders, and diabetes mellitus are responsible for 81% of all NCD-related deaths. It is projected that the worldwide burden of NCDs would rise by 17% by 2025 [4]. Cardiovascular disease is the leading cause of noncommunicable disease death: according to the most recent Global Burden of Disease report, there were over 400 million people living with CVD in 2015, with almost 18 million dying from it. Low- and middle-income countries face death of young age people due to NCD, where 29% of NCD deaths happen whose age is below 60 years, but death rate is 13% in high-income countries. It is also found that cancer incidence, the death rate is going to increase 82% in low and 70% in lower-middle and 40% in high income countries by 2030, compared with 2008 [5-9]. NCDs are a large and growing global burden, previously limited to developed countries, they are now a major issue in the developing world. These trends are driven by population growth, unplanned urbanization, and sedentary lifestyles [10].

1.2 Limitations of Conventional Therapeutic

Treatment of NCDs primarily focuses on controlling and slowing down the disease progression since most of the NCDs are chronic and not completely curable. Antihypertensives such as beta-blockers, ACE inhibitors to control high blood pressure, hypoglycemic agents like insulin, metformin for managing diabetes, statins for lowering cholesterol in cardiovascular conditions, are some common therapeutics used in conventional treatment. While traditional therapies aid in disease control and quality of life, issues such as long-term medication adherence, side effects and healthcare costs highlight the importance of preventative efforts and integrated care approaches.

1.3 Upswing of Nanotechnology in Medicine

The ability to incorporate drugs into nano systems represents a paradigm shift in pharmacotherapy by enabling cell-specific drug delivery, which reduces systemic toxicity and side effects while optimizing drug administration routes [13]. Nanomedicine is a rapidly advancing field to harness the unique properties of nanosized materials to develop innovative approaches for disease diagnosis and targeted drug delivery [14]. The application of nanotechnology in medicine has led to a new concept termed as nanomedicine [15]. Nanomedicine integrates nanotechnology with other scientific disciplines like biology, chemistry, and physical science to combat various diseases [16]. Nanoparticles, typically ranging in size from 1 to 100 nanometers, exhibit distinct physicochemical characteristics, including a high surface-to-volume ratio and tunable surface chemistry, that make them particularly well-suited for biomedical applications [17]. These characteristics enable higher drug loading capacity, improved bioavailability, and precise targeting of specific cells or tissues in the body, thereby optimizing therapeutic effectiveness and reducing unintentional side effects through the development of multiple covalent bonds and appropriate design for use in targeted therapies [18]. The capacity to modify the surface of nanoparticles with various polymers, organic, and inorganic compounds allows for personalized applications, enhancing their utility in drug delivery systems and cancer therapy [19]. Targeted drug delivery, made possible by the unique capabilities of nanotechnology, has become a tangible reality, promising to elevate therapeutic drug concentrations in affected areas while minimizing harm to healthy tissues [20]. Various factors influencing the bioactivity of NPs include surface properties, nano-morphology, physical structure etc. Conjugation of the targeting ligands such as the peptides, small molecules to the surface of the nanoparticles cause a change thereby increasing the efficiency of the systems to target specific cells or tissues and hence enhancing the efficiency therapeutically, thereby lowering the targets effects. The use of polymeric nanoparticles utilization also modifies the surface thereby modifying the efficiency [21,22]. Studies reveal that there is an ease of adherence for the undifferentiated cells on the smooth surface when compared to that of the rough surface [23]. Falagan-Lotsch et al. found that the gold nanoparticles (AuNPs) at a concentration of 0.1nM show some toxic effects on human dermal fibroblasts, thereby modifying the cells significantly with respect to its morphology and gene expression [24]. Borate based MINP has been developed which shows itself to suppress the tumor growth by creating a block in the human epidermal growth factor receptor-2 signaling pathway [25].

2. Bioactive-nanomaterials:

Bioactive nanomaterials are mainly two types bases on their origin: natural nanomaterials and artificial nanomaterials. Gelatin, viruses, natural mineralized materials that comprises shells, corals, bones, wings of insects, opals, fog (aerosol type), leaves of lotus, spider silk, volcanic ash, gecko feet, and ocean spray are some examples of natural nanomaterials [26, 27]. Besides artificial nanomaterials are created through mechanical manufacturing techniques. Depending on their structural composition, there are four types of nanomaterials are recognized [28]. Most commonly used nanomaterials are:

2.1 Bioactive Inorganic Nanomaterials

The primary components of inorganic nanomaterials are inorganic substances [29]. Bioactive Inorganic nanoparticles do not comprise carbon. They are harmless, hydrophilic, stable and are compatible with living systems. Their distinct physical and chemical characteristics allow them to engage with living systems and provoke specific biological reactions. Inorganic nanomaterials encompass a broad spectrum of materials, including metal nanoparticles, metal oxide nanoparticles, ceramic nanoparticles, and quantum dots. Metal oxide-based inorganic nanoparticles are made up

of metal and oxygen, such as zinc oxide (ZnO), iron oxide (Fe_2O_3, Fe_3O_4), titanium oxide (TiO_2), cerium oxide (CeO_2) and aluminium oxide (Al_2O_3). Pure metals like gold, silver, copper, iron, zinc, cadmium, platinum, titanium, cobalt, and palladium are the main components of metal-based nanoparticles. Inorganic solids such as carbides, carbonates, oxides, and phosphates make up ceramic inorganic nanoparticles. One of the best examples of semiconductor nanomaterials is quantum dots.

2.2 Bioactive Organic Nanomaterials

Polymers, lipids, proteins, carbohydrates, and different organic substances are the components of organic nanoparticles (NPs) [30], along with sizes varying from 1-100nm. Liposomes, dendrimers, micelles, and ferritin are some examples of this group. They are usually biodegradable, harmless, and some of them have a hollow core (e.g., liposomes). They are sensitive to light, heat and electromagnetic radiation [31]. Non-covalent intermolecular interactions are typically responsible for their formation [30]. Recently, organic nanoparticles (NPs) have become more and more prominent in the biomedical industry for targeted delivery of drugs [31] and management of cancer [32].

2.3 Carbon-based Nanomaterials

Carbon-based nanomaterials are made up of pure carbon atoms [31]. They are highly stable, low-toxic, and environmentally friendly. Furthermore, due to their excellent anisotropic heat conductivity, carbon-based nanomaterials can be utilized in sophisticated computational devices, where uncooled chips can reach temperatures exceeding 100°C. Carbon black NPs, carbon quantum dots, carbon nanotubes, nano diamonds, and fullerenes are a few types of this class of NPs. The shape of carbon-based nanoparticles varies among the members. Fullerenes have a symmetrical, closed-cage structure, while carbon black nanoparticles are clusters of highly fused spherical particles resembling grapes [33]. The size of carbon quantum dots is (>10) nm and consists of discrete, quasi-spherical carbons [34]. Because of possessing special features such as thigh strength and affinity for electrons, optical, thermal, and absorption properties [35] carbon-based NPs are typically utilized in various fields.

2.4 Bioactive non-metallic Nanomaterials

Bioactive non-metallic nanomaterials primarily consist of non-metallic elements, including selenium nanoparticles, black phosphorus nanosheets, silica nanoparticles, dendrimers etc [36]. These nanomaterials are biologically active and have unique features that make them excellent for various biomedical uses. They are biocompatible, have large surface area, tunable surface chemistry, and can interact with living systems at the nanoscale. These materials exhibit diverse biological activities such as antioxidant [37], antibacterial [38] and anticarcinogenic properties [39] and are utilized in drug delivery, biosensing, and bioimaging.

2.5 Bioactive noble metal nanomaterials

Bioactive noble metal nanomaterials are nanoparticles composed of noble metals like gold, silver, or platinum [40]. They exhibit unique properties at the nanoscale, such as remarkable biocompatibility [41], excellent stability [42], plasmonic resonances [43], catalytic activity [42, 44], etc. These properties make noble metal nanomaterials highly attractive for various biomedical applications [45]. Specifically, their tunable optical [43], electronic [46] and catalytic properties [42, 45] enable the development of innovative strategies for disease diagnosis [42], targeted therapy [47], and non-invasive imaging [48].

2.6. Bioactive Metal Oxide Nanomaterials:

Metal oxides are made up of oxygen and other metals like basic oxides, acid oxides, peroxides, amphoteric oxides, superoxides etc. These materials are highly stable, small in size and have large surface area. Bioactive metal oxide nanomaterials are being explored for their potential in treating non-communicable diseases due to their unique properties and direct biological activity [49]. These materials offer an innovative approach to disease treatment, often without relying on drug release mechanisms [49]. Metal oxide bioactive nanomaterials have been actively involved in cancer treatment. The anticancer activity of different metal oxide nanostructures is primarily due to their physicochemical properties related to intrinsic features, such as their antioxidant activity [50]. Some metal oxides nanostructures like zinc oxide, copper oxide and iron oxide can make cancer cell membranes leak, creating stress in the cells and encouraging the cancerous cells to die. Copper oxide and iron oxide nanoparticles cause the tumor cell membranes to break down by starting processes that lead to cell death, like activating caspase-9 and caspase-3 [51, 52], while Zinc oxide nanoparticles can kill cancer cells by inducing oxidative stress and by causing the cells to die [53].

Iron oxide nanoparticles are used in delivering drugs, in MRI scans and for cancer diagnosis and tissue repair. Because of their magnetic behaviour, these nanoparticles can turn magnetic energy into heat, making them useful for treating cancer with heat. Their magnetic properties can be changed by tuning their size and shape or by mixing them with other metals or making them into clusters [54]. Luo et al. [55] looked into using iron oxide nanoparticles for diagnosing and treating diseases like Alzheimer's, Parkinson's and amyotrophic lateral sclerosis. They studied how these nanoparticles can be used in MRI scans, as contrast agents, and as tools to carry drugs. Titanium dioxide (TiO_2) nanoparticles can cause cancer cells to die when they are exposed to visible or uv light, because they create reactive oxygen species [56]. This property is used to treat cancer through a process called photodynamic therapy.

2.7. Biomimetic Nanomaterials

Biomimetic nanomaterials are nano-sized materials that are made to mimic structures, functions and the methods originating in nature [60]. They get ideas from living systems to create new materials with enhancing properties for use in medicine, the environment and materials science [61]. These materials can replicate the complex designs and features of natural systems, like how proteins can assemble themselves or how viruses can target specific cells [62]. They are used in many ways, like delivering medicine so it can reach the right part of the body at the right time, which makes treatments more effective and causes lesser side effects [63]. Biomimetic nanomaterials offer new pathways to cure various noncommunicable diseases by exploiting nature-inspired designs to enhance drug delivery and therapeutic outcomes [64]. These advanced materials aim to prevail challenges associated with traditional therapies, such as poor targeting and systemic side effects, through their unique biocompatibility and efficient delivery capabilities. Kang et al. [65] explored bionic nanoparticles, with a focus on cell membrane-coated nanoparticles. They found that mimicking the surfaces of red blood cells, white blood cells, platelets, and cancer cells could improve how well drugs are delivered and make the nanoparticles stay in the body longer. Making derivatives of quinazolinone with boric acid groups can mimic neutrophil traps to catch harmful microorganisms, so they can kill bacteria [66]. Some of these biomimetic structures are used as contrast agents in MRI or CT scans to make tissues and issues more visible, helping with early diagnosis and more accurate images [67]. Some nanoparticles can be made to send signals when they attach to specific cells, which allows for real-time tracking of processes in the body. By mimicking the surface features of harmful organisms, these nanoparticles can escape the immune system and reach their targets more effectively [65].

2.8. Bioactive Polymeric Nanomaterials:

Polymeric nanomaterials are colloidal materials of sizes ranging from 10 to 1000 nm and have grabbed numerous attentions due to their high immunogenicity, stability, biodegradability and biocompatibility [68, 69]. The nanomaterials can be easily modified with active ligands for targeting the cells or tissues. By carefully adjusting how polymers are made and choosing the right type of polymer, it's possible to synthesize nanomaterials with desired features like size, charge, water repellent properties and drug release parameters (like fast, controlled, or slow release) [70]. Huang et al. [71] discovered that mixed shell polymer micelles (MSPMs) have a special surface structure made up of both hydrophobic and hydrophilic parts, and they can be used to treat Alzheimer's disease. Sellergren et al. made a sialic acid-engraved nanoparticle furnished with nitrobenzoxadiazole (NBD) fluorescent groups (symbolized as AINP-NBD) which can be used for bioimaging. They reported that AINP-NBD exhibited strong affinity for sialic acid, whereas binding of the competitor glucuronic acid and other monosaccharides were noticeably weaker. This helps the nanoparticle to specifically highlight certain cancer cells based on how much sialic acid they have on their surfaces [72]. Shea et al. designed a polymer nanoparticle by carefully choosing the right monomers and found that the resulting nanoparticles could bind to their target molecules with the same strength and selectivity as natural antibodies [73]. Elmowafy et al. [74] reviewed the different frequently used polymeric materials and their corresponding methods of fabrication, the needs of such systems for natural bioactive agents and the potential role of polymer functionalization, hybrid systems, and using systems that respond to certain signals can help fix problems with these materials.

2.9 Supramolecular based nanomaterials

In healthcare and nanomedicine, supramolecular host-guest systems are of specific interest due to their effectiveness in disease diagnosis and therapeutic activity [75, 76]. There occurs non-covalent interaction between the guest molecules and host compounds which facilitates capturing followed by localization of analytes leading to encapsulation of drug and gene [77, 78]. A large number of macrocyclic host molecules for example calixaranes [79], crown ethers [80], cyclodextrins [81], pillarenes [82] etc. are utilized for developing such supramolecular systems. Mesoporous silica nanoparticles (MSN) due to its porous nature have the ability to store a large number of drug molecules for their controlled release at the targeted sites [83]. Nguyen et al. reported redox mode of activation of supramolecular host-guestmechanism on the MSNs [84]. The stalks of Ferrocenecarboxylic acid served as guest molecules and cyclodextrins served as host molecules in their work. The cargo molecule that is Rhodamine B is released from the pores of MSNs by applying 1 V voltage. It electrochemically oxidises the ferrocene units resulting in dissociation of the host-guest network. This type of redox-active release of drugs has found its application in treatment of cancer [85]. UV light activated functionalization of MSN relies on UV-switchable guest molecules. This activation mechanism was utilized in the pulsatic therapeutic delivery for certain diseases [86]. Other modes of activation include change in pH, competitive binding, enzymatic activation, activation by applied ultrasound, applied magnetic field, applied near-infrared light, sequential activation etc.

3. Mechanisms of Bioactivity in Disease Treatment:

Proteins, cells or tissues in our body produce biological responses with bioactive materials. This has been a wide area of research over the last few years. Bioactive materials have very promising properties like mimicking the bio-matrix for tissue generation, biocompatibility that ensures no immune rejection or inflammation, capability of forming direct chemical bond with surrounding tissues specially bones, stimulating cell adhesion, controlled ion release that helps bone

mineralization, formation of new blood vessels, targeted drug delivery, non toxicity etc. With these properties bioactive materials have large applications in therapeutics, diagnostics and regenerative medicines.

3.1 Mode of action of Silver nanoparticles (AgNPS)

Mikhailova reported the mode of action of AgNPs and their probable bio-applications [87]. It was a topic of interest as silver ions and the suspension of AgNPs are known to have antiviral, antifungal, bacteriostatic, bactericidal effects on a huge number of fungi, pathogenic microorganisms, viruses etc. But their exact mechanism of action is difficult to predict. However, Dakal et. al. reported some basic modes of antimicrobial measures of AgNPs [88]. Highly sophisticated characterization techniques like AFM, FE-SEM, TEM and XRD provide a deep understanding of the plausible mechanism of action [89-91]. The antimicrobial action of AgNPs can be explained by four mechanisms: (1) Adhesion of AgNPs on the surface of the cell wall and the membrane. The positive surface charge on the AgNPs causes an electrostatic pull on the negatively charged cell membrane of the microorganisms, which attaches the AgNPs onto the cell membranes [92]. This shrinks the cytoplasm followed by detachment from the membrane and ultimately cell wall rupture [93]. It is evident from the morphological studies. Raffi et al summarized that only after a short while of contact with AgNPs, the cell wall of *E. coli* cells disrupts completely as evident from transmission electron microscopy [94]. (2) Penetration of AgNPs inside the cell causing the damage of the intercellular structures like mitochondria, ribosomes, vacuoles etc. and biomolecules like proteins, lipids and DNA. There are water filled channels on the outside membrane of the Gram-negative bacteria that are known as porins and these porins uptake the AgNPs into the bacterial cells. The subsequent interactions with the biomolecules and the cellular structures, especially the denaturation of ribosomes damages the microbial cell [95]. (3) Cellular toxicity induced by AgNPs and oxidative stress. This stress is caused by an increase in concentration of Ag^+ ions which is a heavy metal. The property of AgNPs to produce reactive oxidative species or free radicals such as hydrogen peroxide (H_2O_2), singlet oxygen, hypochlorous acid and hydroxyl radical ($OH\cdot$) and is responsible for its antibacterial activity [96] These reactive species cause bacterial cell death as Ag^+ ions attach to the cell membrane that blocks the mitochondrial respiratory function of the microbial cell [97]. (4) Controlling the signal transduction pathways of microbial cells by AgNPs. The pathway of phosphorylation and dephosphorylation is what makes a microbial cell to be alive. The study of the phosphotyrosine profile of bacterial proteins suggests a useful insight into the effect of AgNPs to the transduction pathways of bacterial signal. Inhibiting these pathways would inhibit bacterial cell growth. AgNPs can significantly modulate cellular signaling by the dephosphorylation of tyrosine residues on the targeted bacterial peptide substrate thereby inhibiting the microbial growth [98].

3.2 Mode of action of AuNPs

AuNPs also play an important role in biomedical applications. Several studies reported that biosynthesized AuNPs have antimicrobial properties against certain pathogenic verities like *B. pumilis, E. coli, S. auereus, A. niger* and *A. fumigatus* [99]. They are also reported to show antifungal activity. Cui et al. described two modes of action of antimicrobial activity of AuNPs against multidrug-resistant (Gram-negative) bacteria: (1) Inhibiting the activity of ATPase thereby decreasing the ATP level which in turn degrade the membrane potential (2) Hindering the ribosome subunit to bind with tRNA [100]. AuNPs decreases the ATP levels by down-regulating the F-type synthase activity as shown in *E. Coli*. This results in metabolism failure resulting in cell death. Antifungal activities of AuNPs is mainly attributed to its smaller particles due to which the cell membranes can be easily penetrated. Being a soft acid, gold has a high affinity for the soft bases like DNA having sulphur and phosphorus. This results in the hampering of DNA metabolism for example replication, synthesis etc. which ultimately leads to cell death [101].

3.3 Mode of action of Zinc oxide nanoparticles (ZnONPs)

ZnO NPs also have a vital role in antimicrobial action towards both Gram-positive and Gram-negative bacteria [102,103]. Like AgNPs it can also develop reactive oxidative species from water and oxygen. But ZnONPs coagulate in aqueous media and so are unable to react effectively with the microorganisms. Therefore, Gordon et al. combined FeO and ZnO to incorporate magnetic properties with increased ability for colloidal suspension. This helps in increased antibacterial activity. Biogenic nano-composites exhibited higher antibacterial activity towards *S. aureus* than *E. coli*. The ratio of Zn and Fe decides the extent of antibacterial action [104].

3.4 Mode of action of copper nanoparticles (CuNPs)

CuNPs also showed antimicrobial properties. It is reported to release Cu^{2+} ions which can alter local conductivity and hence pH. It disturbs the bacterial cell membrane interrupting cellular enzyme functions leading to cell death [105]. CuNPs can also disturb the normal functioning of DNA [106]. There are also reports about CuNP-mediated oxidative stress towards the microbes resulting in cell damage [107].

4. Applications of bioactive nanomaterials in Major Chronic Diseases

4.1 Cancer Therapy

Cancer therapy involves techniques aimed at suppressing or destroying cancerous cells through inhibition or radiation. Current cancer treatments are mostly associated with certain risks which escalates the development in enhancing the specificity of anticancer

drugs toward malignant cells while minimizing damage to healthy tissues remains a critical goal. To achieve effective cancer treatment, efficient targeted delivery systems for chemotherapeutic agents or bioactive anticancer compounds are essential and in this perspective, nanoplatforms play one of the best suited role [108]. Nanoparticle (NP) delivery involves three main steps: evading the reticuloendothelial system (RES), crossing tumor capillaries, and penetrating cancer cells. Their tendency to accumulate in tumors enhances treatment effectiveness, and particles over 50 nm are less prone to RES clearance, boosting their therapeutic value [111,112]. In recent years, the application of bioactive nanomaterials in cancer therapy has grown significantly. For instance, Poly (lactic-co-glycolic acid) PLGA-based cell-mimicking nanomaterials coated with natural killer cell membranes have shown the potential to stimulate or enhance the activation of tumor-associated macrophages toward the M1 phenotype, thereby exerting anti-tumor effects [109]. Graphite oxide acetylene (GDYO) can interact with signaling molecules and the gene expression regulator STAT3, contributing to the restoration of the suppressive cancer microenvironment, which in turn improves the efficiency of immune-based cancer therapy [110]. AuNPs offer advantages like high stability, biocompatibility, and tumor-targeting ability due to their surface properties and enhanced permeability. Carriers like DOX-BLM-PEG-Au NPs and EpCAM-RPAnN show strong potential for use in chemotherapy [116]. AuNPs suppress prostate cancer cell growth by downregulating specific metalloproteinases [113]. Copper oxide and iron oxide nanoparticles induce tumour suppressing activity through the activation of caspase-9 and caspase-3-mediated cell death, whereas zinc oxide nanoparticles destroy cancer cells by generating oxidative stress and initiating apoptosis promoting pathways. [114,115]. Chitosan-based nanoparticles loaded with an andrographolide analog have been designed to deliver anticancer drugs specifically to colon cancer sites, where the bioactive compound induces apoptosis in cancer cells [117]. Curcumin-loaded polymeric nanoparticles, another form of biopolymeric nanocarrier, enhance serum stability compared to free curcumin; the bioactive molecule, curcumin, exhibits cytotoxic effects on ovarian cancer by inhibiting tumor growth when irradiated at a low dose [118]. Albendazole-loaded polyurethane nanoparticles have been developed to improve drug delivery efficiency, where albendazole serves as the bioactive agent that enhances anticancer activity by inducing apoptosis in breast cancer cells [119].

Platinum–curcumin complexes encapsulated in pH- and redox-responsive nanoparticles have demonstrated enhanced anti-metastatic activity and synergistic anticancer effects against lung cancer through controlled intracellular drug release, highlighting the growing potential of nanoparticle-based systems in cancer therapy [120].

4.2 Cardiovascular diseases

Cardiovascular diseases encompass a range of circulatory system disorders, whose onset and progression are influenced by various factors, including common risk factors like high cholesterol, high blood pressure, and diabetes; unhealthy habits such as smoking and obesity; and fixed factors like family history [121, 122]. In the context of myocardial infarction, the use of therapeutic nanomaterials allows for the delivery of a large number of drug molecules with the potential for sustained or triggered release, targeting damaged heart tissues [123-127]. Their application in heart tissue engineering is promising, as nanomaterials enhance the structural, conductive, and regenerative properties of cardiac scaffolds, thereby improving outcomes in heart repair and regeneration [128].

A range of nanoparticles has been explored for their potential applications in the therapy and regeneration of vascular and cardiac tissues. AuNPs synthesized via chemical reduction have demonstrated promising results in enhancing conductivity in cardiac patches [129-133]. Similarly, AgNPs particularly those synthesized using ethylene glycol (EG), have been utilized to improve the antibacterial properties of heart valves [134]. Magnetic nanoparticles such as Fe_3O_4 serve effectively as image contrast agents, aiding in cardiac imaging and diagnostics [135-138]. PEGylated liposome nanoparticles targeted with amino acids have shown potential as vehicles for site-specific targeting and drug delivery within the heart, particularly in the post-myocardial infarction (MI) setting [139]. Additionally, lecithin-based nanoparticles carrying vascular endothelial growth factor (VEGF) are employed to promote site-specific regeneration of cardiac tissue after MI [140]. Lipidoid nanoparticles have also gained attention for enhancing the efficacy of gene therapy aimed at cardiovascular regeneration [141]. Moreover, polyester carbon nanotubes contribute to both improved electrical conductivity and mechanical reinforcement of scaffolds used in cardiac tissue regeneration [142]. Platinum (Pt) and palladium (Pd) nanoparticles also have exemplary applications in drug delivery for treating cancer [143,144]. Collectively, these nanomaterials underscore the growing importance of nanotechnology in cardiovascular therapy and tissue engineering.

4.3 Diabetes

Recently, nanotechnology has enabled non-invasive blood glucose monitoring. Various nanoparticles are also being studied for insulin delivery, including biodegradable polymers, micelles, ceramics, dendrimer and liposomes. Polymeric nanoparticles have shown greater effectiveness and efficiency compared to conventional oral and intravenous insulin delivery methods. These nanoparticles, made of biodegradable polymers enclosed within a nanoporous membrane, act as insulin carriers. When exposed to pH changes, the polymer swells and triggers insulin release. Various copolymers such as N,N-dimethylaminoethyl

methacrylate, polyanhydrides, polyurethanes, polyacrylic acids, and polyacrylamide are currently being studied for this purpose [145, 146]. In the case of nanoparticle micelles, the outcome involves encapsulating the drug within surfactant micelles (SMs), which enhances bioavailability as observed in in vivo pharmacokinetic studies [147]. Ceramic nanoparticles—composed of materials such as calcium phosphate, silica, alumina, and titanium—offer several noteworthy advantages. These include ease of fabrication, excellent biocompatibility, ultra-small particle size, and high structural stability. Among them, calcium phosphate nanoparticles are particularly effective and are being explored as carriers for insulin, especially in the development of oral insulin delivery systems [148]. Among several types, poly(amidoamine) (PAMAM) dendrimers are the most popularly used in pharmaceutical and biochemical applications [149]. PAMAM G4, in particular, can reduce blood glucose levels and mimic hypoglycemic drugs without affecting peptide function [150]. In diabetic models, it normalized key markers such as HbA1c, AOPP, AGEs, and aminotransferases. Gold, silver, and zinc nanoparticles have shown promising outcomes in the management of diabetes. AuNPs have been reported to effectively reduce blood glucose levels. Similarly, AgNPs not only help lower blood sugar but also improve dyslipidemia, a common complication in diabetic patients. Zinc nanoparticles further contribute by significantly reducing blood glucose levels, supporting their role as potential therapeutic agents in diabetes treatment [151-153].

4.4 Bioactive nanomaterials in neurodegenerative disorders:

In recent years, the rising proportion of the aging population worldwide has led to an increased prevalence of neurodegenerative disorders (NDs) [154] and accounted for approximately 12% of all global deaths [155]. These disorders are generally characterised by gradual loss of structure and activities of nerve cells of both nervous systems [156, 157] often resulting in neuronal death and significant morbidity. One major challenge in developing therapeutics for neurodegenerative diseases is the difficulty of targeting the brain due to the protective barrier, the blood-brain-barrier (BBB) [158,159]. This barrier acts as defense systems, hindering the penetration of most drugs and medications into the brain [160-165].

Nanomaterials, these advanced systems of drug delivery, hold great promise for efficiently transporting therapeutic compounds to affected areas in the brain [165-167]. Moreover, nanomedicines also modulate disrupted processes associated with neurodegenerative diseases, such as inflammation, oxidative stress, and the accumulation of toxic proteins. Recently, varieties of nanomaterials have been examined against neurogenerative disorders such as AuNPs, SiNPs, CeO_2NPs, QDs, liposomes, DNA-based nanomaterials, and dendrimers [156, 158, 168-173].

Extensive studies on AuNPs are done on AD, stroke, and PDs [156, 174-177]. Development of neurotoxic plaques is a defining feature of AD and interaction with amyloid-beta (Aβ) peptides, AuNPs stops them from clumping together to form neurotoxic plaques [156, 178]. AuNPs can effectively mitigate oxidative stress by reducing the level of harmful Reactive Oxygen Species (ROS). Oxidative stress is associated with the degeneration of dopaminergic neurones in PD. By reducing the quantity of ROS, AuNPs safeguard these vital neurons from damage [156]. AuNPs may also facilitate neuroprotection and support regeneration following a stroke [156, 179]. Recently, Silica nanoparticles with mesopores referred to as mesoporous silica nanoparticles (MSNPs) [180] have gained significant recognition as a promising material for delivering the drug for their distinctive characteristics, like free and large surface area, adjustable pore sizes, and admirable biocompatibility to the BBB and these characteristics make them efficient for delivery of drug to the targeted site [156]. In addition to MSNPs, magnetic nanoparticles have also been developed as valuable tools for drug delivery and neuroimaging [156] due to their distinct physicochemical properties and biodegradability [30]. CeO_2NPs have antioxidant properties whose application has been rising against neurodegenerative disorders. These NPs have neuroprotective effects and therapeutic efficacy against different neurodegenerative diseases [182].

Literature is also available on the potentiality of QDs against neurogenerative disorders, particularly on AD and PD [183,184]. The accumulation and transmission of α-synuclein are related to PD [156, 171, 185,186] and these immature alpha-syn are generally accumulated in the mid-section of the brain, which leads to toxicity [40]. Interacting with mature fibrils Graphene quantum dots (GQDs) cause disaggregation and prevent *α*-syn from fibrillizing. According to Liu et al. [187], in vivo research revealed that GQDs can cross the BBB and prevent the dopaminergic neurones from α-syn preformed fibrils. Carbon quantum dots (CQDs) also showed effective results against brain tumors [42], neuroimaging and neurogenerative disorders [188-189].

4.5 Bioactive nanomaterials in inflammatory diseases:

Recent evidence suggests that rationally engineered intrinsically bioactive nanomaterials can serve as next-generation anti-inflammatory agents to regulate inflammation and treat various acute and chronic diseases [190, 191]. Synthesized $MoSe_2$-polyvinylpyrrolidone nanoparticles can prevent a range of ROS, including hydrogen peroxide, hydroxyl, and oxygen ion and reactive nitrogen species such as 2,2-diphenyl-1-picrylhydrazyl in mitochondria and cells [192]. ZnO nanoparticles exhibit colonic anti-inflammatory potential and can suppress pro-inflammatory cytokines (IL-1β and TNF-*α*) and myeloperoxidase [193]. Selenium nanoparticles protected the intestinal barrier by activation of Nrf2 and

its downstream genes against inflammatory damage caused by oxidative stress [194]. Anti-inflammatory properties of synthesized glycine and acryloyl-based polymeric nanoparticles, GlyNPs are reported [195].

4.6 Nanoparticles in autoimmune disease therapy

Nanoparticle technology offers innovative methods to treat autoimmune diseases by enhancing immune tolerance and minimizing side effects. These particles carry disease-specific autoantigens to induce targeted immune tolerance. NPs can be engineered to implement antigens and drugs directly to antigen-presenting cells (APCs) [196]. Nanoparticles promote the growth of regulatory T-cells (Treg) and inhibit harmful T-cell activation. Various types of nanoparticles, viz. polymeric nanoparticles and liposomes, have been used to deliver drugs like methotrexate or dexamethasone in rheumatoid arthritis (RA), decreasing inflammation with lower toxicity. Additionally, nanoparticles can be depicted to target and inhibit pathogenic immune cells by delivering immunomodulatory drugs, such as cyclosporine A, to reduce systemic toxicity [197]. Functionalizing the particles with specific ligands enables targeted delivery to activated macrophages and other immune cells. Furthermore, Pang et al. (2023) [198] reported PLGA nanoparticles loaded with insulin peptides for treating another autoimmune disease (Type 1 Diabetes). Targeting strategies can enhance the conveyance of anti-inflammatory compounds to specific tissues. Wu et al. (2021) [199] reported that iron oxide nanoparticles are used for non-invasive imaging of inflammation and tracking immune cell recruitment. Similarly, integrating CRISPR/Cas9 technology with nanotechnology enables precise genome editing and therapeutic control [200]. Besides, AuNPs are also utilized for photo-thermal therapy and imaging in autoimmune skin diseases such as psoriasis [201]. These nanoparticles can induce tolerogenic dendritic cells, promoting immune tolerance. [202].

4.7 Nanoparticle based therapy for gastrointestinal disorders

The limitations of traditional diagnostics have provided the pathway to innovative nanomaterial-based diagnostic tools have emerged as promising alternatives, offering improved sensitivity and specificity for detecting and monitoring GI diseases [203]. For example, anti-CEA maghemite nanoparticles combined with surface-enhanced Raman scattering (SERS) have been used to detect CEA-expressing cells with high specificity, facilitating the identification of tumors, micro metastases and circulating cancer cells [204]. Similarly, carbon nanoparticles have proven effective and safe for CRC detection and lymph node mapping during laparoscopic surgeries [205]. AuNPs have also shown potential for the non-invasive detection of CRC through SERS, offering high sensitivity and specificity in serum samples [206]. In the context of IBD, nanomaterial-based diagnostics are producing encouraging results. For instance, dextran-coated cerium oxide nanoparticles (Dex-CeNPs) have been employed with CT imaging to accumulate at inflamed sites in colitis, providing enhanced contrast [207]. Lanthanide-doped nanocrystals have also been used for near-infrared fluorescence (NIRF) imaging, enabling real-time 3D visualization of the GI tract in animal models, potentially advancing non-invasive diagnosis and monitoring of IBD [208].

Cutting-edge nanoparticle-based drug delivery systems are transforming GI disease treatment by precisely targeting affected regions, thereby improving therapeutic outcomes and minimizing adverse effects [209]. The GI tract has many physiological barriers that limit the effectiveness of conventional therapy methods. To address these obstacles, bioactive nanocarriers—such as polymeric nanoparticles, liposomes, and SLNs—are being explored as viable alternatives [210].

Persistent *H. pylori* infection can be difficult to eliminate completely, but advances in nanomedicine provide promising new strategies. For example, targeted nanocarriers can exploit *H. pylori*'s surface adhesion mechanisms to increase bacterial eradication rates. NPs functionalized with fucose-based ligands bind to the bacterium's fucose-binding proteins and adhesins, boosting antibiotic concentration at infection sites [211]. Similarly, urea-linked nanocarriers like chitosan nanoparticles can penetrate bacterial cells and simultaneously inhibit urease activity, disrupting pH homeostasis and making *H. pylori* more vulnerable to gastric acid [212]. Mucoadhesive nanocarriers enhanced with chitosan, pectin, hyaluronic acid (HA) improve confinement in the gastric mucosa, sustaining drug release [213]. Recent developments in engineered nanocarriers, including polymeric nanoparticles, lipid-based nanoparticles, bio-membrane-coated systems and metallic nanoparticles have demonstrated notable potential for improving drug stability, bioavailability, and therapeutic outcomes in gastritis treatment [214-215]. For example, lipid nanocarriers like CLA-Bi-ZnO_2@Lipo loaded with clarithromycin exhibit strong antibacterial effects, reduce mucosal inflammation, and help maintain gut microbiota balance [216]. Likewise, polymeric hydrogels such as AASP-CMCS-NAC-C16N-DCA have shown promise in eradicating *H. pylori*, protecting gastric tissues, and promoting mucosal healing [217].

Gastric cancer remains a major worldwide health interest, designating amidst the most frequent and fatal malignancies due to late-stage detection, aggressive progression, and the limitations of traditional chemotherapy, which is often accompanied by significant toxicity [240]. Nanotechnology-based approaches offer potential solutions by enhancing drug stability, solubility and enabling both passive and active aiming of tumor tissues through the improved permeability and retention (EPR) effect or ligand-mediated binding [218]. Various nanocarriers—such as liposomes, polymeric and metallic nanoparticles, and dendrimers—are being developed to deliver chemotherapeutic drugs, gene therapies, or

immunotherapies directly to gastric tumors, maximizing local drug concentrations while minimizing systemic side effects [219]. Additionally, pH-sensitive and stimuli-responsive nanoparticles provide controlled release in the acidic tumor microenvironment, improving treatment selectivity and sparing healthy tissues [220]. Multifunctional theragnostic nanoparticles that integrate diagnostic and therapeutic capabilities are also being explored to empower real-time monitoring of treatment reaction [221]. While notable progress has been made, ongoing challenges include achieving precise tumor targeting, scaling up production, and ensuring long-term safety [222].

Similarly, inflammatory bowel diseases (IBD)—comprising Crohn's disease (CD) and ulcerative colitis (UC) —are relapsing inflammatory, chronic conditions of the GI tract that remain difficult to manage [223]. Conventional treatment regimens often rely on glucocorticoids (e.g., prednisone), 5-aminosalicylic acid derivatives (e.g., sulfasalazine) and various immunosuppressive agents (e.g., azathioprine, tacrolimus and mercaptopurine), which have yielded reasonable therapeutic benefits [224, 225]. However, these drugs typically lack targeted specificity, leading to widespread distribution in organs such as the liver, kidneys, and blood vessels, that can generate off-target effects and toxicity. Furthermore, long-term and repeated use increases the risk of developing multidrug resistance [226]. In this context, nanomedicine-based drug delivery systems (DDSs) are emerging as a promising approach in IBD management, offering innovative solutions to enhance therapeutic precision and overcome some limitations of traditional treatments [227]. Nanotechnology offers a promising alternative by improving site-specific drug transport and enabling supervised release directly at inflamed regions. Various nano formulations—comprising polymeric nanoparticles, liposomes, SLNs, and dendrimers—have been designed to shield drugs from degradation in the harsh GI environment and reveal them precisely where inflammation occurs [228]. Functionalization with specific ligands or surface coatings enhances mucoadhesion and targeting of diseased intestinal tissue [229]. Additionally, nanoparticles are being explored to deliver anti-inflammatory peptides, probiotics, siRNA, and even gene-editing tools, offering innovative ways to modify the disease course [230]. Although further clinical validation and safety studies are still needed, the expanding research strongly suggests that nanoparticle-based treatments could significantly improve outcomes for patients with IBD by providing more targeted, effective, and patient-friendly therapeutic options.

4.8 Nanoparticle applications in respiratory diseases

The therapeutic potential of different nanomedicine formulations has been validated in preclinical models for diseases like asthma, chronic obstructive pulmonary disease (COPD), lung infections, pulmonary fibrosis, lung cancer and other respiratory disorders, demonstrating their capacity to improve disease outcomes [231]. A range of NPs have exhibited potential therapeutic effects, opening up new avenues for developing novel treatments that could enhance drug efficacy while minimizing adverse effects [232, 233]. Nanotechnology, through the precise manipulation of materials at the nanometer scale, has become a transformative field with broad applications in medicine [234]. Specifically, the use of nanoparticles in treating respiratory diseases is highly promising due to their capacity to interconnect intricately with biological systems at the cellular and molecular levels [235]. Their high superficial area-to-volume ratio facilitates efficient drug encapsulation, precise targeting, and controlled release, all of which are critical for optimizing therapeutic outcomes while limiting systemic toxicity [236]. The ability to deliver therapeutic agents precisely and enhance their effectiveness while minimizing side effects creates new possibilities for managing a wide range of respiratory conditions [237]. Moreover, nanoparticles can be engineered to penetrate biological barriers, such as the lung's mucus layer, and target specific diseased cells or tissues, thus improving treatment precision [238]. Their fusion into respiratory therapies holds substantial potentiality for enhancing patient consequences and modernizing clinical practice. Nanomedicines are being explored as next-generation treatments for chronic respiratory conditions. Notably, nanoparticles can extend the half-life of drugs, ensuring the efficient delivery of active pharmaceutical ingredients to target sites via nanocarriers [239]. The versatility of nanomedicines, from component modification and surface functionalization to the encapsulation of multiple therapeutics within a single platform, makes them well-suited to overcome challenges such as chemoresistance [240]. The triumph of nanotherapy in the lungs based on multiple components, comprising the administration route, nanoparticle characteristics, toxicity profiles, and the specific physiological conditions of the diseased lung [241]. In asthma, a chronic inflammatory airway disease marked by reversible obstruction and airway hyperresponsiveness, nanoparticles enable targeted drug delivery that may significantly improve outcomes and reduce systemic exposure [242]. Encapsulation of corticosteroids, bronchodilators, or anti-inflammatory agents within nanoparticles allows direct delivery to inflamed airways, enhancing efficacy and minimizing side effects. In tuberculosis treatment, inhalable nanoparticles can maintain sustained drug levels in the lungs, achieving better outcomes than traditional oral administration, while bioadhesive systems further enhance drug absorption and reduce dosage requirements [243]. In diagnosing COVID-19, nanoparticles enable targeted chemotherapy delivery, minimizing toxicity and improving patient tolerance [244].

5. Toxicity, Biocompatibility, and Regulatory Considerations:

Safe interaction of biological tissues and nanomaterials is dependent on various factors like different size, surface area and design, zeta potential, polydispersity index and composition of chemicals otherwise it will be toxic to the cells and tissues [245].

The size of nanoparticles causes toxicity. The toxicity responses induced by ultra fine particles is higher in comparison with larger sizes of similar composition [246-249]. Silver NPs of 20 nm are more toxic than the larger NPs. [250]. Having more penetrability smaller sized nanoparticles are more toxic. Bare small sized nanoparticles are more toxic [251]. Sometimes it causes damage to the genetic materials [252]. Improper doses of nanomedicines cause damage to the lungs, liver, kidney, heart and spleen. Routes of exposure like tropical or oral routes are better than other exposure. In the workplace or in laboratories exposure of nanoparticles are more common and inhaled easily [253]. Inhalation of Carbon NPs causes rapid translocation into the circulation. Gold NPs affect cell proliferation and cause DNA damage. Gold NPs with spherical shape can be more easily uptake than the rod shaped [254]. Like gold, Titanium dioxide (TiO_2) of 20 nm induced 43-times inflammation than 250nm in rats [255]. Lengthwise-oriented nanoparticles, nanorod zinc oxide (ZnO) particles are more toxic than the spherical ones on human lung epithelial cells of definite size [256]. The GNPs were biocompatible materials at low concentrations [257]. A number of nanoparticles such as metaloxide nanoparticles, fullerenes and silica particles can cause reactive oxygen species (ROS) generation in cell-free systems [258-261]. The toxicity of NPs can be removed using various surface modification techniques. Before using clinically, toxicity and biocompatibility of the nanoparticles have to be carefully evaluated, with emphasis on an understanding of the physio-chemical properties for understanding adverse biological responses [262]. Biocompatible nanomaterials are synthesized to reduce toxicity, decrease adverse effects in the gastrointestinal tract, and enhance immune response. Nanomaterials can target organs and tissues[263]. Before using NPs surface chemistry, size, shape, concentration, and dosage and material composition are examined, as they significantly influence the biological response [264].

Positively charged nano-particles and the negative cell membranes have more interaction [265-266]. Cationic nanoparticles are more active than neutral or anionic nanoparticles [267]. Hydrophilicity, hydrophobicity, topography of surface, tension can do protein adsorption, platelet activation, growth of cell, and biocompatibility [268] .

There is no unique protocol for in vivo biocompatibility studies and several different procedures can be adapted to investigate the safety and efficacy of a specific nanomaterial in vivo. There are no harmonized standards for evaluating toxicity and biocompatibility of nanomaterials in biological systems and the rules still need to be investigated. Due to the huge beneficial effect along with its toxic effect and biocompatibility of nanoparticles it has become prime importance that this science can be regulated. Use of nanoparticles should be safe. Kraegeloh et al., [269] developed the 'safe-by-design' concept for safe development of Nanoparticles.

6. Discussion:

The utilization of bioactive nanomaterials in biomedicine offers enhanced possibilities for the treatment of most of the NCDs. Their capacity to improve treatment efficacy, permit accurate drug administration, and reduce side effects has made bioactive nanomaterials vital tools in addressing some of the most complicated and chronic human health issues. Nanomaterials have transformed cancer therapy by increasing the bioavailability and tumor-specific targeting of chemotherapy drugs. Nanomaterials' regenerative and conductive capabilities allow for improvements in heart tissue engineering and imaging. Gold and silver nanoparticles improve scaffold conductivity, whereas PEGylated liposomes and lecithin-based NPs enable targeted delivery and recovery following a myocardial infarction. In the case of diabetes, nanocarriers such as polymeric nanoparticles, dendrimers, and liposomes improve insulin delivery and non-invasive glucose monitoring. pH-sensitive carriers enable controlled insulin release, but metal-based nanoparticles such as gold and zinc have glucose-lowering properties, providing additional or alternative therapeutic methods. Nanomaterials have developed as precise immunomodulators for inflammatory and autoimmune illnesses. Their surface activity permits the targeting of inflammatory cytokines, oxidative stress pathways, and immune cell interactions. The role of bioactive nanomaterials in respiratory illnesses is also promising. Nanoparticles provide site-specific delivery for chronic diseases such as asthma, COPD, and tuberculosis. Inhalable nanomedicines and smart nanocarriers react to environmental cues like pH or redox states, increasing bioavailability and decreasing off-target effects. Bioactive nanomaterials have well-documented antibacterial and anti-infective properties, which is especially important given the rise in antimicrobial resistance. Metallic nanoparticles (Ag, ZnO, TiO_2) have inherent antibacterial properties, while polymeric and lipid-based carriers improve medication transport and tissue targeting. Furthermore, stimuli-responsive nanocarriers are the future of precision antimicrobial therapy. Bioactive nanomaterials, with their versatility, biocompatibility, and engineering flexibility, are crucial to the future of customized and precision medicine.

7. Challenges and Future Perspectives:

The widely used nanomaterials have some kinds of limitations during use. The cost of nanoparticle doses are very high, not possible to use by common people. Besides, the laboratory experiments are carried out on rats, mice, pigs and rabbits and these doses are not applicable to the human body. Again, due to high cost pigs are not extensively used but pigs skin is more

analogous to human skin as compared to mice, rats and rabbits [270]. Proper use of nanoparticles can cure various kinds of infection and wounds. But sometimes it causes irritation, allergies, skin inflammation and psoriasis [271-272]. Therefore, it is necessary to use bio-safety measures to control this kind of side effect. Sometimes nanoparticles can cause DNA damage, reduce gene methylation which finally causes cancer to the body [273-274]. Sometimes it causes death to the animals if not used properly. It also causes problems while pregnant. The cost of nanoparticles is very high and not affordable for common people. The cost of nanomaterial has to be reduced for the sake of common people. The side effects caused by nanoparticles have to be reduced for its proper application in the human body. New and advanced technologies and methods have to be investigated to reduce the side effects caused by nanoparticles. Nanomaterials have the ability to respond to some stimuli of environmental contaminants and their remediation but it faces several challenges, including its toxicity and environmental risks, issues related to their stability and scalability and regulatory challenges [275]. Plant extracts are the mostly accepted biological medium for the formation of NPs as they are more stable, reduce metal ions more quickly, and more active against micro-organisms. As NPs have many side effects on the tissues and environment, attention must be paid to environmental and societal implications of these nanoparticles.

8. Conclusion:

Due to the escalating global burden of NCDs, there is always a requirement of alternatives to conventional therapeutics. Bioactive nanoparticles offer further treatment possibilities for various illnesses. This critical review emphasizes the revolutionary potential of bioactive nanomaterials for the prevention, detection, and management of major NCDs such as cardiovascular disease, gastrointestinal diseases, diabetes, cancer, chronic inflammatory diseases, respiratory diseases and neurodegenerative illnesses. Bioactive nanomaterials are pioneering precision medicine and next-generation healthcare by providing site-specific drug delivery, increased bioavailability, reduced toxicity, and multifaceted therapeutic potential. Unlike traditional nanomedicine preparations that release drugs, bioactive nanomaterials do not exert drug release, but interact with proteins, cells, or tissues in vivo to cause biological reactions for treatment of diseases. However, progress of bioactive nanomaterials face many challenges, further research is needed to understand the structure-activity relationship of bioactive nanoparticles based on their unique physical and chemical features, including size effect, interface effect, and mechanical characteristics; which will help to design and develop these materials.

Funding: This research received no external funding.

Conflict of Interest: The Authors declares no conflict of interest in the manuscript.

Data Availability Statement: No new data were created or analyzed in this study.

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