VOLUME 11 ISSUE 2 2025

ISSN 2454 – 3055

INTERNATIONAL JOURNAL OF ZOOLOGICAL INVESTIGATIONS

Forum for Biological and Environmental Sciences

Published by Saran Publications, India

International Journal of Zoological Investigations Vol. 11, No. 2, 604-615 (2025)

International Journal of Zoological Investigations
Contents available at Journals Home Page: www.ijzi.net
Editor-in-Chief: Prof. Ajai Kumar Srivastav
Published by: Saran Publications, Gorakhpur, India

ISSN: 2454-3055

A Review on Pharmacological Traits of Strontium Nanoparticles and Their Combination with Other Nanoparticles/Biomaterials

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Received: 6th November, 2024; **Accepted:** 22nd May, 2025; **Published online:** 7th October, 2025

https://doi.org/10.33745/ijzi.2025.v11i02.056

Abstract: Nanotechnology is the fundamental tool in the architecture of nanoparticles. The nano-scaled particles tailored through nanotechnology has wider applications in the diverse areas. Applying physio-chemical protocols the designing of nanoparticles has been successfully done. But the usage of greater pressure, temperature, toxic solvents and cumbersome instruments has shifted the nanoparticle fabrication to biological mode where microbes and plants are adopted for harnessing the nanoparticles. The phyto-extract applied designed nanoparticles are well opted for the medical province. Among vast types of metallic nanoparticles, recently strontium nanoparticles have attracted the research community owned to its biomedical functions. Moreover, strontium has conveyed function similar to magnesium and calcium in the human system and adopted in the bone engineering. Furthermore, the nanoparticles of strontium and their combination with other nanoparticles or biopolymers have presented efficacious anti-proliferative, antimicrobial, anti-inflammatory, anti-diabetic and anti-radical functions. In the recent few years, the fabrication of the strontium nanoparticles applying the extracts of plants has been done to utilize them tremendously in the medical field. Moreover, the phyto-engineering of the strontium nanoparticles are safer, easier, lower-cost and eco-friendly.

Keywords: Nanotechnology, Nanoparticles, Phyto-extract, Strontium nanoparticles

Citation: Sasikala S., Padmini R. and Charumathy M.: A review on pharmacological traits of strontium nanoparticles and their combination with other nanoparticles/biomaterials. Intern. J. Zool. Invest. 11(2): 604-615, 2025.

https://doi.org/10.33745/ijzi.2025.v11i02.056

Introduction

Designing and manipulating any bulkier materials for opting nanometric dimensional structures are the chief concern of nanotechnology. Nano-particles are the prime content of the nanotechnology and generally owns one nanometric to hundred nanometric dimension (Iravani *et al*., 2014). Basically, it is a technology integrating various diverse scientific disciplines such as chemistry, physics, engineering and biotechnology. The fabricated nano-scaled materials contain inherent exceptional qualities such as greater surface area: volume, mechanical, optical and electrical features that are entirely devoid in their counter sections (Onyeaka *et al*., 2022). Nanoparticles appear in diverse dimension, morphology and forms (inorganic nanoparticles, organic nanoparticles, carbon-based nano-particles, metal as well as metal-oxide based nanoparticles) (Khan *et al*., 2022).

The nanoparticles are the perfect candidate in the 21st century for functioning in interdisciplinary zones that include remediation of environment, cosmetics, food, cultivation, medicines and clothing owned to their miscibility and biological system availability (Bajpai *et al*., 2018). Procuration of nanoparticles was done applying two diverse approaches that includes top-down fabrication approach and bottom-up fabrication approach to design nanoparticles of varying dimension and morphological features. In the first type of approach, the material bulkier part is broken down to offer materials owning nano-dimension. The second approach of engineering nanoparticles is quite opposite to the first approach, here the smaller materials are gathered to design nano-structures (Baig *et al*., 2021). Presently, the designing of nanoparticles of metallic (silver, gold and platinum) or metal oxide nature (zinc oxide, copper oxide, titanium oxide) are in trend and exploited in the biomedical sections for delivering drugs, bio-sensing gadgets, bio-imaging and tissue engineering as scaffolds (Radulescu *et al*., 2023). By applying the physio-chemical to biological methodologies the fabrication of metallic nanoparticles was done. The biological and the chemical protocols are categorized in the bottom-up approach and physical methods in to-down fabrication approach (Vijayaram *et al*., 2024).

The physical and the chemical methodologies such as spray pyrolysis, sputter deposition, laser ablation, evaporation-condensation, mechanical milling, chemical reduction, thermal decomposition and micro-emulsion are applied to procure nanoparticles of desired nature, dimension and morphology (Dikshit *et al*., 2021; Bordiwala, 2023).The usage of cumbersome equipment, discharge of baneful chemicals into the eco-system, higher pressure and temperature consumption has made the physical as well as chemical methodologies unsuitable for designing the nano-scaled particles (Ying *et al*., 2022; Murgueitio Herrera *et al*., 2024). To overcome the glitches of the physio-chemical approaches, green fabrication is applied for harnessing the nanoparticles and termed as nanobiotechnology. The greener harnessing of metallic nanoparticles is eco-friendly, pocket-friendly and does not require greater pressure/temperature. Another benefit is that most of the greener synthesis of nanoparticles occurs at room temperature making the methodology more feasible (Abuzeid *et al*., 2023). In the greener designing of metallic nanoparticles non-toxic reducing/stabilizing agents are mostly opted which eradicate the production of toxic secondary products. Different microbes (algae, fungi, yeast and bacteria) and plants are adopted for the tailoring of metallic nanoparticles (Thatyana *et al*., 2023). The microbial-based harnessing of nanoparticles is costlier in contrast to the phyto-based synthesis. Moreover, the tedious isolation, variable setting and biohazard risks are prominent in the microbe applied synthesis of nanoparticles (Chopra *et al*., 2022).

The synthesis of metallic nanoparticles using the extract of plants is superior comparative to the microbial applied fabrication protocols. The phyto-extract offers toxic free reducing medium for harnessing stabilized nanoparticles with easier scaling-up (Drummer *et al*., 2021). Different parts of plants (root, leaves, stem-bark, flower and seeds) are employed for producing the metallic nanoparticles. The phyto-active metabolites in the extract of plant organs such as phenolic acids, flavonoids, amino acids, saponins, proteins, alkaloids, terpenoids, glycosides, quinones and tannins facilitates the bio-based reduction of precursor metal salt ions to form metallic nanoparticles (Soltys *et al*., 2021; Begum *et al*., 2022). In addition to bio-reduction the phyto-active compounds participate in the stabilization and capping of the fabricated nanoparticles

(Coman *et al*., 2024).The phyto-based harnessing of metallic nanoparticles does not create any environmental hazardous secondary-products (Mittal *et al*., 2013). Moreover, the metallic nanoparticles obtained by using extracts of plants are biocompatible and practised in biomedical area. The phyto-ingredients layered on the metallic nanoparticles enriches its biological functioning (Jeevanandam *et al*., 2020).

In nature, strontium (Sr) exist in fossil fuels, soil and rocks as soft and silvery type of metal and it is grouped in the periodic table as alkaline earth metal (Kaysım *et al*., 2024). It has similar function to magnesium and calcium in the human body. The strontium formulated or conjugated types of nanoparticles are applied in the delivery of drugs, therapy of cancer, engineering of bone tissues, dentistry as cavity filler, immunotherapeutic, bio-imaging, gas sensing gadgets and environmental cleaning such as treatment of wastewater (Mukherjee and Mishra, 2021).

Biomedical applications of Strontium nanoparticles

Regeneration of bones by the strontium nanoparticles

Bone is a form of scaffold tissues providing structural support to the body, safeguarding the vital internal soft tissues/organs, aid in locomotion, blood cell production through bone marrow, storage of calcium along with phosphate and regulating endocrine functions. The bone tissues are incorporation with inorganic part (calcium phosphate) into the protein matrix of collagen (Type-1) (Šromová *et al*., 2023).The bone tissue structural as well as compositional level differs based on the genetically inheritance, age factor and the life-style followed by the individual (Garcia *et al*., 2021).

The bone tissue fabrication involves the functioning of two forms of cells namely osteoclast and osteoblast. The osteoclast cells are engaged in the resorption of bone and removing out the older cells whereas the osteoblasts are amenable for the formation of new bone. This process is dynamically balanced for maintaining the required body mass in the human system through various signalling pathways and hormones (parathyroid hormones)(Hanga-Farcaș *et al*., 2023).Generally, normal remodelling of bone tissue is crucial for the healing of fracture for mechanical functioning of the body along with the maintaining homeostasis of calcium. When there is too much resorption done by the osteoclasts with minimal new bone formation it negatively impacts the bone balance causing loss of bone mass and bone related disease (osteoporosis) (Florencio-Silva *et al*., 2015).

Strontium has similarity to calcium and plays pivotal function by enhancing the bone formation and diminishes the resorption of bone by the osteoclasts. This is executed by the activation of various signalling pathways concerned with the bone cells and applied as a common treatment of osteoporosis in old age and post-menopausal condition (Naveau, 2004). Usually, strontium as strontium ranelate has proven to be safer first-line anti-osteoporotic medicine and shown to enhance the bone strength and mass when given as 2 g/day (Boivin *et al*., 2012). It was identified that the strontium as well as calcium nanoparticles incorporated in the MOFs (metal-organic framework) porous natured material and the strontium nanoparticles alone has triggered the enhanced secretion of bone matrix by the osteoblast and suppressed the resorption by the osteoclastic cells in the hBMSC cell line. Strontium NPs/Calcium NPs has also shown to promote the expression of the RUNX2 transcriptional gene activity along with its phosphorylation. Upsurge in the expression of gene related to collagen formation was also noticed. The ALP (alkaline phosphatase) activity in the osteogenic cells treated with SrNPs/CaNPs and SrNPs occurred dictating the osteogenic form of differentiation capacity of the nanoparticles (Farasati Far *et al*., 2023).

Meka *et al.* (2016) designed nSrCO3 (strontium carbonate nanoparticles) and created a nanocomposite type of fibrous scaffold using poly (ε-caprolactone) through co-electrospinning technique and checked the osteogenesis activity. The strontium ions released as 65 ppm from the scaffold dictated the profound mesenchymal stem cell proliferation. The mineral deposition was also increased up to 4-folds further suggesting the enriched osteogenesis through the upsurged presentation of osteogenic markers (RunX-2, BMP-2 and osterix). Thus, suggesting the utility of scaffold containing strontium in engineering of bone tissue (Meka *et al*., 2016).

Junkai Zeng *et al.* (2020) found that Sr-CPS designed through the substitution of strontium in the calcium phosphate silicate bioactive ceramics demonstrated excellent osteogenesis through the upregulation of Wnt/β-catenin signalling pathway and halted the osteoclastogenesis by the downregulation of NF-κB signalling pathway in the rBMSCs. Also, the ALP activity was greater in the rBMSCs conveying the osteogenic form of differentiation (Zeng *et al*., 2020). The Sr-BG (strontium-doped bioglasses) with alginate-chitosan as Alg/Cs/Sr-BG were designed through sol-gel methodology dictated greater mechanical stableness and enhanced differentiation of the cells in contrast to the Alg/Cs (alginate-chitosan) and Alg/Cs/BG (alginate-chitosan-bioglass) scaffolds presenting the applicability of Alg/Cs/Sr scaffolds for bone repairing in severe damages (Manoochehri *et al*., 2022).

Anticancer trait of Strontium nanoparticles

Cancer displays the unmanageable cellular proliferation along with the growth due to abrupted cellular signalling (Anand *et al*., 2023). Globe-wide, next to cardiovascular diseases, cancer holds the title of major mortality cause (Boutros *et al*., 2021). Normally, chemotherapy, radiation and surgery are utilized for treating different forms of cancer. The anticancer drugs are loaded with certain side effects and can also harm healthier cells in long run (Chandra *et al*., 2023). Medicinal plants are beneficial in cancer cell killing in contrast to the chemotherapeutic medicines (Khalid *et al*., 2022). Many anticancer drugs have been isolated from the medicinally important plants and few of them are commercialized after being approved by Food and Drug Administration (Singh *et al*., 2016). The bioavailability of anticancer drugs has been enhanced by utilizing nanocarriers for the designated drug delivery (SC-9; Mohapatra *et al*., 2022). Not only anticancer drugs but also phyto-derived bioactive anti-proliferative compounds are also tagged or loaded with metallic or other nanoparticle forms for their efficacious delivery (Ajith *et al*., 2023).The metallic nanoparticles lyse the cancerous cells by damaging the DNA, producing ROS, apoptosis, cellular cycle arrest, caspase activation, mitochondrial dysfunction and gene silencing (Roshani *et al*., 2023; Perumal *et al*., 2024).

The nano-based delivery of MAPK SiRNA and p53 gene through the LCSNPs (small-ligand coated strontium nanoparticles) halted the proliferation of the breast cancerous cells (MCF-7) when evaluated by MTT assay. Usually, the function of p53 (a cancer suppressor) molecule is lost during the onset and the progressive phases of cancer. In the executed study, the MCF-7 cell viability was lost up to 70% (Bakhtiar *et al*., 2022).The SCNs (Strontium carbonate nanoparticles) designed as nanocarrier for the anticancer drug (etoposide) to release the anti-proliferative drug in a controlled way. The SCNs and the ESCNs (etoposide loaded strontium carbonate nanoparticles) were checked for their anti-proliferative performance towards the HEK-293T (normal human embryonic kidney cells) as well as cancerous cell line (SGC-7901: Human gastric carcinoma cell line) at four different doses (5 μg/ml to 40 μg/ml). The viability of the normal cell line remained unaffected whereas the survival of the gastric cancer cells was diminished with the increase in the dose as well as duration of exposure (24 h and 48 h) by the ESCNs in contrast to the SCNs (Qian *et al*., 2012).

Aloufi (2023) designed $SrSnO_2$ (strontium-doped tin dioxide) applying the extract of *Mahonia bealei*and assessed for its anti-proliferative function against the breast cancer cell line (MCF-7). The nano-rod shaped $SrSnO_2$ particles were efficaciously able to hinder the proliferation of MCF-7 cells in a dose-influenced form when tested from 5 µg/ml to 20 µg/ml. After 48 h of exposure of the cells to $SrSnO_2$ nanoparticles the viability of the MCF-7 was tremendously affected and the IC_{50} concentration was measured as 14 µg/ml in the executed experiment (Aloufi, 2023).

Antimicrobial activity of Strontium nanoparticles

Microbial infections are the severe threat to the human life and the incidence of MDR (multidrug-resistance) strains of microbes are rapidly upsurging as the present antibiotic has lost their bactericidal performance (Álvarez-Martínez *et al*., 2021).The overuse of antibiotics has tuned up the resistance mechanism in the microbes towards the antibiotics (SM-11; Natalia Vaou *et al*., 2021). The antibiotics are proven to cause gastro-intestinal troubles, hypersensitive reactions and haematological alterations (Pancu *et al*., 2021).The phyto-extract applied metallic nanoparticles either alone or linked with antibiotics efficacious kills the microbial cells (Loo *et al*., 2018; Taha Yassin *et al*., 2024). The nanoparticles opting various modes such as membrane disruption, dysfunction of mitochondria, enzymatic degradation and via ROS generation causes lysing of microbial cells (Sharmin *et al*., 2021).

The antibacterial potency of the SR (strontium ranelate)-loaded (PLGA) microspheres was designed and incorporated with HANPs (hydroxyapatite nanoparticles) and AgNPs (silver nanoparticles). The bactericidal potency of the created microsphere (SR-PM-Ag-HAT) was evaluated through spread plate technique. The SR-PM-Ag-HAT and SR-PM-Ag displayed efficacious bactericidal potency against the MRSA (methicillin-resistant *Staphylococcus aureus*) and *Staphylococcus epidermidis* in comparison to the PM and SR-PM. Also, there was noticeable decrease in the genesis of biofilm by SR-PM-Ag-HAT and SR-PM (Mao *et al*., 2018). The STFx/Sr-Ti-xFexO3-δ) known as strontium titanium ferrite designed by mingling Fe_2O_3 and strontium oxide through mechanochemical route was investigated for its bactericidal potency. The nanoparticles $STF_{0.8}$ brough great reduction in the population of *Escherichia coli* in a shorter duration (less than 15 min). The exterior positive charge, strontium ion dissociation, alkaline pH and the nano-dimension of the $STF_{0.8}$ were attributable for the bacterial killing (Zhang *et al*., 2014).

Using sol-gel supercritical fluid drying methodology HAP (hydroxyapatite) nanoparticles, SrCaHAP (Strontium-half substituted hydroxy-apatite) nanoparticles and SrHAP (strontium totally substituted hydroxyapatite) nanoparticles were designed and assessed for their bactericidal potency. It was found in the executed study that the maximum zone of inhibition was presented by the SrHAP in comparison to HAP and SrCAHAP. The inhibitory zone presented by the SrHAP against the *Escherichia coli* was 23 mm, *Lactobacillus* was 21 mm and *Staphylococcus aureus* was 17 mm (Lin *et al*., 2008). SrCPCs (strontium doped calcium phosphate cements) when incorporated with the nanoparticles of hydroxyapatite (HA-NPs) along with antibiotic tetracycline has shown to be efficacious in presenting bacteriostatic as well as bacterial lysing traits against the *Staphylococcus aureus* and *Escherichia coli* (Dapporto *et al*., 2022).

The irregularly shaped strontium oxide nanoparticles procured by blending the extract of *Elodea canadensis* and strontium nitrate solution was assessed for its antibacterial function through disc-diffusion methodology. The fabricated greener strontium oxide nanoparticles were able to display bactericidal activity towards the tested *Escherichia coli* with maximum inhibitory zone of 22 mm and 20 mm for *Bacillus subtilis* at 24 µg/ml. At the other screened doses (3, 6 and 12 µg/ml) a slight inhibitory zone developed around the disc. Precisely, the antibacterial activity of greenly procured strontium oxide nanoparticles was completely done-based (Anbu *et al*., 2022). The strontium nanoparticles procured using the extract of oolong tea demonstrated microbicidal activity against the tested bacterial and fungal strains with profound inhibitory zone. Here, 23 mm inhibitory zone was developed against

Streptococcus mutans and *Enterococcus faecalis* and the greater inhibitory zone was developed for *Staphylococcus aureus* as 33 mm. The screened fungal strain (*Candida albicans*) presented inhibitory zone of 9 mm (SM-5/B)(Sumedha *et al*., 2023).

The strontium nanoparticles harnessed applying the solution of strontium nitrate and leaf extract of *Ocimum sanctum* were screened for its bactericidal function through agar-disc diffusion methodology. In the antibacterial assay, it was confirmed that the strontium nanoparticles were able to inhibit the development of both gram-positive as well as gram-negative forms of bacteria by creating an inhibitory zone. Both *Klebsiella pneumonia* and *Pseudomonas aeruginosa* presented an inhibitory zone of 10 mm and the zone of inhibition of 9 mm was seen for *Morganella morganii*. The lowest inhibitory zone of 5 mm was appeared for *Proteus vulgaris* (Apsana *et al*., 2018). Oxide form of strontium nanoparticles fabricated applying the leaf extract of *Lantana camara* has shown to be microbicidal towards the *Aspergillus niger*with 20 mm inhibitory zone and *Escherichia coli* with 21 mm inhibitory zone at investigated 100 µl dose (Ilavenil *et al*., 2023). Strontium nanoparticles harnessed using the extract of green tea conveyed antibacterial and antifungal properties at 100 µl towards the screened *Streptococcus mutans*, *Enterococcus faecalis* and *Candida albicans* (Agarwal *et al*., 2022).

Anti-inflammatory activity of strontium nanoparticles

Inflammation happens in the living system as a shielding response against the wounded tissues or microbial infections. Acute inflammatory conditions are resolved quickly whereas prolonged inflammatory condition creates damage to the tissues and macromolecular upsurging the incidence of chronic health illnesses (Soares *et al*., 2023). Inflammation is usually characterized by certain signs that include swelling, redness, heat and pain due to the release of inflammatory biomarkers from the damaged site (Gallo *et al*., 2017). The NSAIDS (non-steroidal anti-inflammatory drugs) implemented for tackling inflammatory condition when given for longer period display side-effects on the human system (Bindu *et al*., 2020). The phytochemicals of plants and the metallic nanoparticles procured from the phyto-extract displayed anti-inflammatory functions (Gonfa *et al*., 2023). Metallic nanoparticles display their anti-inflammatory trait by hindering the proliferation of mast cells, iNOS (inducible nitric oxide synthase) suppression, inhibiting the release of pro-inflammatory chemicals (cytokines), declining ROS formation and blocking the NF-κB signalling pathway (Agarwal *et al*., 2019).

Strontium oxide nanoparticles tailored using the extract of *Suaeda monoica*, a mangrove herb of Chenopodoaceae family has shown anti-inflammatory activity when assessed through BSA (bovine serum albumin) protein inhibition methodology in a dose-dependent manner when tested from minimum (5 µg/ml) to maximum (100 µg/ml) concentration (Sinha *et al*., 2024).The strontium nanoparticles procured applying the extract of *Acacia nilotica* provided dose-based reduction in the percentage inhibition of albumin protein when evaluated through EA (egg albumin) and BSA denaturation inhibition assays (Gopika *et al*., 2023). Using the extract of carrot (*Daucus carota*) the fabrication of strontium nanoparticles was executed and investigated for its anti-inflammatory potency through BSA and membrane stabilization assays. Both the performed assays showed concentration-related inhibition in the protein (albumin) denaturation inhibition. As the dose of the strontium nanoparticles increased the inhibitory percentage of denaturation raised when tested from 10 µg/ml to 50 µg/ml)(Gannamaneni *et al*., 2024).

The phyto-engineering of strontium nanoparticles was done utilizing the extract of *Mimosa pudica* and assessed for anti-inflammatory property through EA assay and membrane stabilization assay. In the executed experimental study, it was noticed that the strontium nanoparticles caused inhibition in the denaturation of egg albumin protein from 52% to 78% when scrutinized from 10 μg/ml to 50 μg/ml). Similarly, through membrane stabilization assay, it was identified that the percentage of red blood cell membrane stabilization was raised from 52% to 79% when screened with aforementioned doses of strontium nanoparticles. Here, anti-inflammatory drug (diclofenac sodium) used gave 81% and 82% of anti-inflammatory activity for EA and the membrane stabilization assay (Harshini *et al*., 2024).

Antidiabetic activity of strontium nanoparticles

Diabetes mellitus is defined as the disorder of metabolism of energy pathway (carbohydrate) along with other vital biomolecular (protein and lipid) pathways. In type-1 diabetes mellitus, the damaged pancreatic β-cells fails to produce the needed insulin whereas the non-functioning of insulin is noted in the type-2 diabetes mellitus (Dilworth *et al*., 2021). In both the types of diabetes mellitus the hyperglycemia is observed leading to the oxidative stress situation and related diabetic complications (Kifle *et al*., 2022). As per the survey provided by the World Health Organization, diabetes mellitus is one of the prime reasons for morbidity and fatality in the global population (Chentli *et al*., 2015).

Acarbose, miglitol and voglibose are used as antidiabetic oral drugs to control the hyperglycemic condition in the diabetes mellitus by halting the functioning of carbohydrate digestion enzymes (alpha-amylase and alpha-glucosidase) and decreases the post-prandial glucose level in the blood (Dar *et al*., 2024). Alpha-amylase of saliva and the pancreatic juice and alpha-glucosidase in the intestinal brush border converts the polysaccharide (starch) to simpler sugar molecules (Ogunyemi *et al*., 2022). The antidiabetic drugs have shown to induce side-effects such as vomiting, headache, abdominal pain, nausea and organ toxicity (Padhi *et al*., 2020). Phyto-based formulated nanoparticles being easily soluble, non-toxic and biological compatible have been reported in the literature for managing diabetes mellitus of both types (Anand *et al*., 2017).

Vallinayaki and Shanmugan (2024) reported that the strontium nanoparticles phyto-designed utilizing the *Mimosa pudica* leaf aqueous extract has shown to decline the performance of α-amylase and α-glucosidase enzymes in a dose-proportional form when assessed from 10 μg/ml to 50 μg/ml dose. The maximum inhibition in the activity of alpha-amylase enzyme after exposure to strontium nanoparticles was 85% whereas, the inhibition in the function of alpha-glucosidase was noticed as 65% to 85% by the screened doses of the tested nanoparticle. For both the assays, acarbose was used for comparative purpose (Vallinayaki and Shanmugam, 2024). Applying the peel aqueous extract of pomegranate fruit and the solution of strontium nitrate were amalgamated to synthesize strontium nanoparticles and investigated for its anti-diabetic efficacy applying 5 μg/ml to 160 μg/ml through alpha-amylase and alpha-glucosidase enzyme inhibition assay. At 160 μg/ml, the inhibition in the function of alpha-amylase was 79% with and IC_{50} dose of 38.07 μg/ml. The inhibition of activity of alpha-glucosidase was 76% with an IC_{50} concentration of 30.59 μg/ml. The acarbose showed an IC_{50} concentration of 34.21 μg/ml (for alpha-amylase) and 29.42 μg/ml (for alpha-glucosidase). Overall, the screened strontium nanoparticles and the positive control (acarbose) conveyed dose (Royapuram Parthasarathy *et al*., 2023). Chen *et al.* (2019) have demonstrated that the greater concentration of strontium in the plasma is associated with the declined risk of type-2 diabetes mellitus and IGR (impaired glucose regulation) (Chen *et al*., 2020).

Antioxidant activity of strontium nanoparticles

Reactive nitrogen species (RNS)/Reactive oxygen species (ROS) as free radicals are generated as a secondary product in the living cells due to metabolic events. Usually, at little quantity the free radicals aid in cellular signalling and defensive functioning within the living creatures (Valko *et al*., 2007). The antioxidative compounds break the cascade of free radicals and guards the system from the harmful consequences by contributing electrons. Both endogenous as well as exogenous antioxidants are engaged in quelling the free radicals (Scheibmeir *et al*., 2005). Oxidative stress emerges when the antioxidative system becomes unable to combat the too much generated free radicals causing damage to the indispensable bio-organic macromolecules (lipids, proteins and nucleic acid) (Halliwell, 2011). Cancer, liver diseases, renal diseases, lung diseases, cardiovascular diseases, cataract, diabetes mellitus and rheumatoid arthritis are stimulated by the excessive free radicals in the human body (Chaudhary *et al*., 2023).The plant derived antioxidants are much safer than the synthetic antioxidants as they have reported carcinogenicity in the body. The medicinal plants own antioxidative traits due to the presence of vast and diverse forms of phytochemicals (Lobo *et al*., 2010). The nanoparticles designed from the phyto-extract dictates antiradical activity due to the presence of polyphenolics, flavonoids, tannins, anthocyanin, coumarin and other phyto-contents (Balkrishna *et al*., 2021; Jafri *et al*., 2022).

The strontium nanoparticles designed using the aqueous leaf extract of *Acacia nilotica* leaves were assessed for their antiradical activity through DPPH and hydrogen peroxide assay. Screened was done applying 10 µg/ml to 50 µg/ml doses of strontium nanoparticles. In the DPPH assay, it was noticed that strontium nanoparticles were potently able to inhibit the DPPH radical and at 50 µg/ml, 90.12% of DPPH radicals were inhibited. Similarly, at the tested highest concentration, the inhibition of hydrogen peroxide radical was 87.40% by the strontium nanoparticles (Gopika *et al*., 2023). Similarly, the strontium nanoparticles procured applying the extract of *Mimosa pudica* when assessed through hydrogen peroxide assay, FRAP assay and DPPH assay, dictated antiradical activity in a dose-related form (Vallinayaki *et al*., 2024). Joseph Linoj *et al.* (2024) have phyto-designed strontium nanoparticles using the extract of *Daucus carota* and revealed that the fabricated strontium nanoparticles were able to quell the free radical presenting their antiradical activity in a concentration-applied mode through three antiradical assays (FRAP, hydrogen peroxide and DPPH assay) (Linoj *et al*., 2024).

Conclusion

In the present period, the nanotechnology has conveyed nano-dimensional materials for applicability in the vast sectors. Strontium nanoparticles are employed in the various provinces. Due to the similarity with the magnesium and calcium, the strontium is used in the biomedical province specifically in the tissue engineering of bone. Additionally, the nanoparticle form of strontium and their blend with other nanoparticles or biomaterials has offered anticancer, antimicrobial, anti-inflammatory, anti-radial and antidiabetic activities. Owned to vast pharmacological benefits the nanoparticles of strontium are synthesized applying the phyto-route. More studies have to be executed to identify the pharmacological benefits of strontium nanoparticles through mechanistic approaches to adopt them in the biomedical sectors as a raw material.

Ethical Statement

This is a review article hence no Ethical Approval needed.

Author Contributions

Each author has contributed equally to the study's planning, analysis, writing, and editing. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare no conflicts of interest.

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