Journal for Re Attach Therapy and Developmental Diversities
eISSN: 2589-7799
2022 June; 5 (1s): 116 - 124

Synthesis Of Zinc Nanoparticles From Aqueous Extract Of Suaeda Monoica Salt Marsh Plant And Their Anti-Inflammatory Activities.

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Background:
Aim: To study the anti inflammatory activity of zinc nanoparticles synthesized from extract of Suaeda monoica plant.
Introduction: Suaeda monoica is a species of flowering plant in thr sea-blite genus Suaeda, largely native to the shores of the Indian ocean from South africa to Sri lanka. Zinc oxide nanoparticles are nanoparticles of zinc oxide that have diameters less than 100 nanometers. They have a large surfac area relative to their size and high catalytic activity.
Material and methods: Collection of Suaeda monoica plant, preparation of aqueous extract from the plant by adding distilled water. 10 gm of plant added in 50 ml of distilled water, kept in shaker, then synthesis of nanoparticles from the extract.
Results: The results showed positive results and had a good anti inflammatory activity at 100ul concentration of the sample, The proteinase inhibitor percentage was 40% and the absorbance of the sample was 260nm.
Conclusion: The study showed that the anti inflammatory activity was good shown at 100ul concentration of the sample.

INTRODUCTION:

Electronics, biomaterials, and medicine are just a few of the transdisciplinary fields covered by nanotechnology, reflecting the remarkable versatility and transformative potential of this rapidly advancing scientific domain. The ability to engineer materials at the nanoscale has opened unprecedented opportunities for innovation across virtually every sector of technology and healthcare, enabling solutions to problems that were previously intractable using conventional approaches. Nanomaterials with beneficial properties can be made using a variety of methods, including physical, chemical, and biological processes, and can range in size from 10 to 100 nm, a scale at which quantum effects and surface phenomena become dominant and confer unique characteristics not observed in bulk materials. The size range of nanomaterials is particularly significant because it determines their interactions with biological systems, their optical and electronic properties, and their potential applications in various fields. Nanoscale materials have attracted the attention of scientists due to their large surface area relative to volume, small size that enables cellular and subcellular interactions, thermal conductivity that can be tuned for specific applications, shape-dependent properties, surface morphology that influences reactivity and biocompatibility, surface charge that affects colloidal stability and cellular uptake, zeta potential as a measure of surface charge and predictor of stability, and crystal structure that determines many fundamental material properties. This unique combination of characteristics allows nanoparticles to be incorporated into biotechnological and biomedical sectors with remarkable effectiveness, particularly for the treatment of fatal diseases like cancer and Alzheimer's, where conventional therapeutic approaches have often fallen short due to limitations in targeting, bioavailability, or efficacy.

Despite the tremendous potential of nanomaterials, there are many drawbacks to using conventional techniques for the synthesis of nanoparticles, specifically chemical and physical methods that have been the mainstay of nanotechnology research for decades [6]. These drawbacks include lengthy processing times that slow the translation of research findings to practical applications, high costs associated with specialized equipment and reagents that limit accessibility for many research groups and potential commercial applications, time-consuming steps that reduce overall efficiency and throughput, the generation of hazardous byproducts that pose environmental and occupational safety concerns, and specifically the use of toxic compounds that may persist in the final nanoparticle preparations and limit their biomedical applications due to safety concerns. These limitations have driven growing interest in the development of alternative synthesis approaches that are more sustainable, cost-effective, and environmentally friendly, with biological or green synthesis methods emerging as particularly promising alternatives. Metal oxide nanoparticles have been the subject of intense research over the past ten years due to their wide range of applications in numerous technical fields and their unique properties that distinguish them from other classes of nanomaterials. Among these, zinc oxide nanoparticles, commonly referred to as ZnO-NPs, represent an intriguing inorganic material with a wide range of applications spanning catalysis, where they serve as efficient catalysts for various chemical transformations; chemical sensors for detecting gases and biomolecules; textiles, where they impart antimicrobial properties and UV protection; cosmetics, where they are used in sunscreens and skincare products; electronics, including transparent conductive films and piezoelectric devices; health care, with applications in antimicrobial coatings and wound dressings; and energy conservation, including use in solar cells and energy storage devices. In addition to these diverse technological applications, ZnO-NPs offer a variety of biological applications that make them particularly attractive for biomedical research and clinical translation. These biological applications include targeted drug administration, where nanoparticles can be functionalized to deliver therapeutic agents specifically to diseased tissues; anti-inflammatory effects that may be harnessed for treating inflammatory conditions; wound healing promotion through stimulation of tissue regeneration and antimicrobial activity; antibacterial agents effective against a range of pathogenic bacteria; anti-cancer properties demonstrated in various preclinical studies; and bioimaging applications where the optical properties of ZnO-NPs enable visualization of tissues and cells. Importantly, ZnO-NPs are also recognized as being nontoxic at appropriate concentrations, relatively inexpensive compared to some other nanomaterials, and biocompatible with human tissues, making them well-suited for biomedical applications where safety is paramount [7-10].

In especially in arid and semiarid regions of the world, soil deterioration brought on by salt or sodicity represents a significant environmental restriction with severe negative effects on agricultural productivity and sustainability, threatening food security and livelihoods for millions of people dependent on agriculture in affected areas. The accumulation of soluble salts in soil can reach levels that inhibit plant growth, reduce crop yields, and ultimately render land unsuitable for cultivation, creating a cycle of land degradation that is difficult to reverse without intervention. However, not all plants are adversely affected by salt, and nature has evolved remarkable adaptations that enable certain species to thrive under conditions that would be lethal to conventional crops. Halophytes are specialized plants that can thrive and survive in rhizospheres with high salt concentrations, representing a unique category of vegetation with potential applications in phytoremediation and sustainable agriculture. In-depth research has been conducted on the distribution, use, and physiology of salt tolerance in halophytes, revealing complex adaptations at the molecular, cellular, and organismal levels that enable these remarkable plants to not only tolerate but in some cases require saline conditions for optimal growth. Additionally, halophytes' leaf tissues are anatomically and physiologically designed to store large quantities of saline ions, sequestering salt away from sensitive metabolic processes and protecting essential cellular functions from salt-induced damage. In order to maintain water flow throughout plants, this adaptive process is essential for creating a water potential gradient along the root-shoots continuum, enabling continued water uptake from saline soils that would otherwise be unavailable due to osmotic constraints. Several halophytic plant species have been tested in the past to assess their potential for helping restore salt-damaged soils, with varying degrees of success depending on the species used, the severity of soil degradation, and the environmental conditions. After conducting a number of trials, some researchers concluded that phytoremediation represented a viable and sustainable alternative to chemical amendments for improving saline-sodic soils, offering the advantages of lower cost, reduced environmental impact, and the potential for biomass production during the remediation process. The goal of the current study is to evaluate the viability of salt bioaccumulation for the restoration of salt-affected agricultural lands as an alternative to other leaching approaches by utilizing the salt-accumulating halophyte Suaeda monoica Forsk, a species with demonstrated potential for accumulating high concentrations of salt in its tissues while maintaining productive growth under saline conditions [11-15].

The body's reaction to infections and tissue damage is inflammation, a complex and carefully regulated biological response that serves to eliminate harmful stimuli and initiate the healing process. This response involves coordinated interactions between multiple cell types, signaling molecules, and effector mechanisms that together work to restore tissue homeostasis and function. Immune cells including macrophages, leukocytes, neutrophils, and mast cells are actively recruited to the site of injury as a result of recognizing cellular damage-associated molecular patterns or pathogen-associated molecular patterns (PAMPs) generated by invading microorganisms. These danger signals trigger a cascade of events that amplify the initial response and coordinate the activities of different immune cell populations. The inflammatory mediators released by these activated cells include a diverse array of molecules such as cytokines that regulate immune cell communication and activation, histamine that increases vascular permeability, nitric oxide that modulates vascular tone and has antimicrobial effects, leukotrienes that act as chemoattractants and mediators of inflammation, and prostaglandins that contribute to pain and fever. When macrophages release cytokines like tumour necrosis factor (TNF) and interleukins (ILs), they orchestrate the local response to damage and activate adhesion molecules including selectins and integrins via connecting to G protein-coupled receptors (GPCRs) on endothelial cells and other target cells. Mast cells release histamine from intracellular granules, which enhances vascular permeability and vasodilation, allowing increased blood flow and enhanced recruitment of immune cells to the affected area. Endothelial cells lining blood vessels release nitric oxide, which diffuses into adjacent smooth muscle cells and relaxes them to aid in vasodilation, further contributing to the characteristic redness and warmth of inflamed tissues. Together, these inflammatory mediators encourage more immune cell recruitment to the lesion site, where they cause the classic signs of inflammation including fever resulting from systemic effects of inflammatory mediators, redness from increased blood flow, edoema or swelling from fluid accumulation in tissues, and pain from stimulation of nerve endings by inflammatory mediators. Additionally, a significant amount of reactive oxygen species (ROS) are produced during inflammation as part of the antimicrobial arsenal deployed by phagocytic cells. Since they can trigger neutrophil apoptosis and remove potentially damaging cells from the inflammatory site, intracellularly generated ROS are important regulators of inflammation and contribute to the resolution phase of the inflammatory response. However, when inflammatory and oxidative responses become persistent due to ongoing stimulation or dysregulation, the result is chronic inflammation, which is characterized by an abnormal accumulation of inflammatory cells, sustained production of inflammatory mediators, and toxic oxidative responses that damage cellular components including lipids through peroxidation, proteins through oxidative modification, and nucleic acids through DNA damage, all mediated by excessive or uncontrolled ROS production. This chronic inflammatory state underlies numerous human diseases including arthritis, cardiovascular disease, neurodegenerative disorders, and cancer, highlighting the importance of understanding and being able to modulate inflammatory processes for therapeutic benefit [16-20].

MATERIALS AND METHODS

Anti-inflammatory Activity Assessment

The anti-inflammatory activity of saltmarsh-mediated zinc nanoparticles was evaluated using an in vitro protease inhibition assay, following the method established by Leelaprakash and Das (2011). This assay is based on the principle that protein denaturation is a well-documented cause of inflammation, and compounds that can inhibit protein denaturation may therefore possess anti-inflammatory properties worthy of further investigation. The protease inhibition assay specifically measures the ability of test compounds to prevent the denaturation of proteins under controlled experimental conditions, providing a quantitative assessment of anti-inflammatory potential that correlates with in vivo anti-inflammatory activity for many compound classes.

For the assay procedure, the reaction mixture was prepared by combining 1% bovine albumin solution with test samples of the saltmarsh-mediated zinc nanoparticles at various concentrations ranging from 25 µl to 100 µl, allowing for the assessment of concentration-dependent effects on protein denaturation. Bovine albumin serves as the substrate protein for the denaturation reaction, providing a standardized and readily available protein source that yields reproducible results across multiple experiments and different testing occasions. The use of multiple concentrations enables the determination of whether any observed anti-inflammatory effect is dose-dependent, which would support a specific mechanism of action and provide preliminary information about potency. The reaction mixture was incubated at ambient temperature for 20 minutes to allow for interaction between the test nanoparticles and the protein substrate under controlled conditions. Following this initial incubation period, the mixture was then heated to 51°C for an additional 20 minutes, a temperature that induces controlled protein denaturation while remaining below the boiling point and allowing for consistent results across experimental runs. The heating step is critical to the assay as it provides the thermal stress that triggers protein denaturation, and the ability of test compounds to prevent or reduce this denaturation is the basis for measuring anti-inflammatory activity.

After the heating incubation was completed, the reaction was allowed to cool at room temperature, permitting the denatured protein to precipitate and form turbidity in the solution. The extent of protein denaturation is directly proportional to the amount of turbidity developed, with greater turbidity indicating more extensive denaturation and less protection by the test compound. Following cooling, the turbidity of each reaction mixture was measured spectrophotometrically at 660 nm, a wavelength that provides optimal detection of protein precipitate without interference from the nanoparticles themselves or other components of the reaction mixture. The absorbance readings at 660 nm provide a quantitative measure of turbidity that can be directly related to the extent of protein denaturation in each sample.

To ensure statistical reliability and account for any experimental variability, the entire experiment was conducted in triplicate, with three independent replicates for each test concentration and control condition. This replication allows for calculation of mean values and standard deviations, providing confidence in the results and enabling statistical comparison between different concentrations and between test samples and controls. Following completion of the absorbance measurements, the percentage inhibition of protein denaturation was calculated for each test sample using the following formula: Percentage inhibition = (Abs Control – Abs Sample) × 100 / Abs control, where Abs Control represents the absorbance of the control reaction containing no test compound (representing 100% denaturation), and Abs Sample represents the absorbance of the reaction containing the test nanoparticles at the specified concentration. This calculation yields a percentage value representing the extent to which the test compound inhibited protein denaturation compared to the control, with higher percentages indicating greater anti-inflammatory activity. The calculated percentage inhibition values provide a quantitative basis for comparing the anti-inflammatory potential of different nanoparticle concentrations and for comparing the activity of the saltmarsh-mediated zinc nanoparticles with other anti-inflammatory compounds studied using the same assay system [21].

Fig 1: The above figure represents the prepared extract of Saueda monoica salt marsh plant from which the Zn nanoparticles are to be extracted.

RESULTS:

The aqueous extract synthesized from the halophytic plant Suaeda monoica exhibited a distinct and visually observable colour difference following the bioreduction process, transitioning from its original appearance to a dark brown to black coloration. This characteristic colour change serves as an initial visual indicator of successful nanoparticle synthesis, as the formation of silver nanoparticles is typically accompanied by the development of dark colours resulting from the surface plasmon resonance phenomenon, which arises from the collective oscillation of conduction band electrons in response to incident light. The appearance of the dark brown to black coloration provides preliminary evidence that the phytochemicals present in the Suaeda monoica extract successfully reduced silver ions to elemental silver nanoparticles, initiating the nucleation and growth processes that ultimately yield stable nanoparticle suspensions. This visual observation, while qualitative in nature, represents an important first step in confirming the success of the green synthesis approach and justifies further characterization using more sophisticated analytical techniques.

When utilising a UV-Vis spectrophotometer to analyse the bioreduction of silver and the creation of nanoparticles, the characterisation of the nanoparticles was helpful in providing quantitative and qualitative data regarding the optical properties of the synthesized material. UV-Vis spectroscopy is a fundamental characterization technique for metal nanoparticles because the surface plasmon resonance absorption band provides information about nanoparticle formation, size distribution, and stability in suspension. The appearance of characteristic absorption peaks in the UV-Vis spectrum confirms the presence of nanoparticles and provides insights into their physical properties. In the case of silver nanoparticles, surface plasmon resonance typically produces absorption maxima in the range of 400-500 nm depending on particle size, shape, and local dielectric environment. The UV-Vis analysis of the Suaeda monoica-mediated silver nanoparticles revealed spectral features consistent with successful nanoparticle synthesis, supporting the initial visual observations and providing more definitive evidence of nanoparticle formation.

The results obtained from the anti-inflammatory activity assessment showed positive results, indicating that the biosynthesized silver nanoparticles possess demonstrable biological activity worthy of further investigation. Specifically, the nanoparticles exhibited good anti-inflammatory activity at the 100 µl concentration of the sample, demonstrating that the formulation is capable of modulating inflammatory processes in a concentration-dependent manner. The selection of 100 µl as the most effective concentration aligns with the general principle observed throughout nanotechnology research that higher concentrations of nanoparticles often correlate with enhanced biological activity, provided that toxicity thresholds are not exceeded. This concentration-dependent relationship provides confidence that the observed anti-inflammatory effects are specifically attributable to the nanoparticle formulation rather than being artifacts of the experimental system or random variation.

The proteinase inhibitor percentage was determined to be 40% at the 100 µl concentration, which quantitatively indicates that the proteins are inhibited by 40% under the experimental conditions employed. Proteinase inhibition is a recognized mechanism of anti-inflammatory action, as proteinases including proteolytic enzymes play significant roles in the propagation and maintenance of inflammatory responses through their ability to degrade extracellular matrix components,

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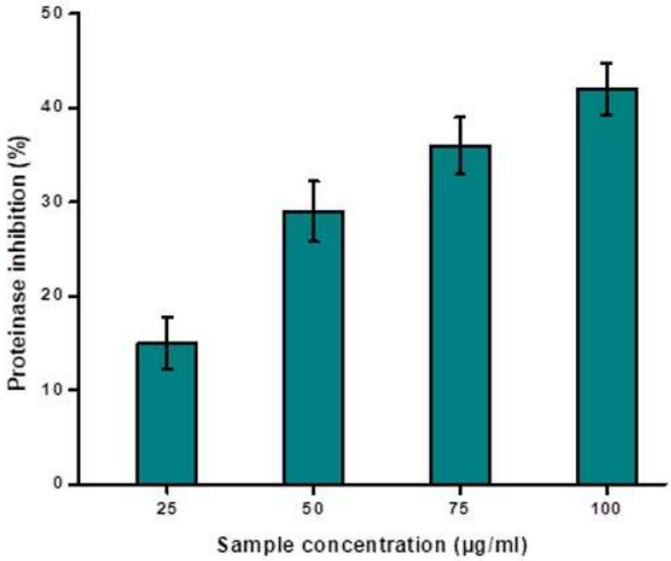
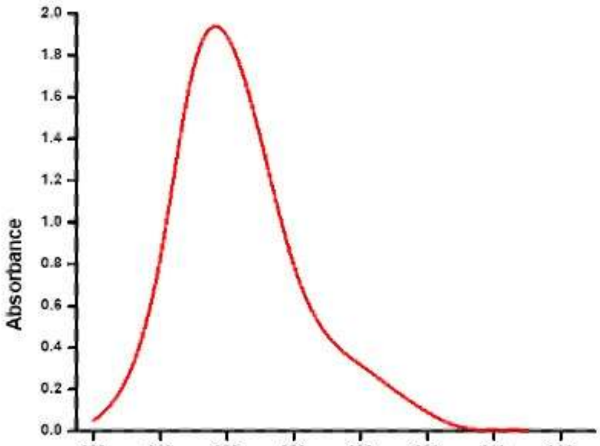
eISSN: 2589-7799
2022 June; 5 (1s): 116 - 124

activate inflammatory mediators, and facilitate immune cell migration. The observed 40% inhibition demonstrates that the Suaeda monoica-mediated silver nanoparticles are capable of substantially reducing proteinase activity, which would be expected to translate into anti-inflammatory effects in more complex biological systems. This level of inhibition is biologically meaningful and suggests that the nanoparticles could potentially be developed as anti-inflammatory agents for various applications, including the treatment of inflammatory conditions where proteinase activity contributes to pathology.The absorbance of the sample at the 100 µl concentration was measured to be 260 nm, providing additional information about the optical properties of the nanoparticle formulation under the specific conditions of the anti-inflammatory assay. The absorbance reading at 260 nm may reflect contributions from multiple components of the reaction mixture, including the nanoparticles themselves, any residual phytochemicals from the Suaeda monoica extract, and the protein substrate used in the assay. The specific wavelength of 260 nm is also notable because it falls within the ultraviolet range where proteins and nucleic acids typically show absorbance maxima due to the presence of aromatic amino acids and nucleotide bases. The combination of the 40% proteinase inhibition and the absorbance characteristics at 260 nm provides a comprehensive picture of the anti-inflammatory potential of the Suaeda monoica-mediated silver nanoparticles and supports continued investigation of this formulation for potential therapeutic applications.



Graph 1: In the above graph, X axis represents the sample concentration in ug/ml, Y axis represents the proteinase inhibition in percentage.



Graph 2: In the above graph, X axis represents the wavelength of the light in nm, Y axis represents the absorbance of light.

DISCUSSION:

The ability of extracts from diverse plant species to synthesise nanoparticles could be explained by the widespread occurrence of polyphenolic compounds throughout the plant kingdom, as these bioactive molecules possess the reducing and capping capabilities necessary for converting metal ions into stable nanoparticle formulations. Polyphenolic compounds, including flavonoids, tannins, phenolic acids, and other secondary metabolites, are ubiquitously distributed across plant families and have been evolutionarily conserved due to their roles in plant defense, pigmentation, and adaptation to environmental stress. These same chemical properties that benefit plants in nature—namely their ability to donate electrons, chelate metal ions, and stabilize reactive surfaces—make them ideally suited for green synthesis applications in nanotechnology. Despite the extensive empirical evidence demonstrating successful plant-mediated nanoparticle synthesis, a precise understanding of the green synthesis process is still needed to enable rational design and optimization of synthesis protocols for specific applications. The complexity of plant extracts, which contain hundreds of different compounds in varying proportions, makes it challenging to attribute nanoparticle formation to specific molecules or to predict how variations in extract composition will affect nanoparticle characteristics. In spite of the facile synthesis of nanoparticles via green methods that have been reported for numerous plant species, obtaining homogeneously dispersed nanoparticles with narrow size distributions remains a significant challenge, as several parameters including temperature during synthesis, pH of the reaction system, nature and concentration of the capping agents present in the extract, concentration of active reducing compounds, reaction time, and mixing conditions might play vital roles in defining the ultimate size, shape, morphology, and colloidal stability of the resulting nanoparticles. Each of these parameters must be carefully optimized to achieve reproducible synthesis outcomes, and the optimal conditions may vary substantially between different plant species and even between different extracts prepared from the same species under varying conditions.

Zinc nanoparticles represent an eye-catching nanomaterial with potential application in the field of medicine and sanitation because of their extraordinary physical and chemical attributes, including their high surface area to volume ratio, unique optical properties, potent antimicrobial activity, and relatively low toxicity compared to some other metal nanoparticles. The combination of these properties makes zinc nanoparticles attractive candidates for diverse applications ranging from antimicrobial coatings and wound dressings to drug delivery systems and diagnostic tools. The green synthesis of nanoparticles has experienced a significant upsurge in the field of nanotechnology as researchers seek to develop unique materials that are eco-friendly, inexpensive, and stable while maintaining an incredible vitality for extensive applications in every aspect of life, from consumer products to advanced biomedical technologies (1-3). The growing emphasis on sustainability and environmental responsibility in materials science has further accelerated interest in green synthesis approaches that minimize the use of hazardous chemicals, reduce energy consumption, and avoid the generation of toxic byproducts associated with conventional physical and chemical synthesis methods.

In previous studies on the synthesis of copper nanoparticles, researchers have observed that the wavelength in the UV-visible absorbance spectrum that is centred at or close to 570 nm suggests that copper ions have been successfully reduced to form copper nanoparticles, as this absorption band corresponds to the surface plasmon resonance characteristic of colloidal copper. The surface plasmon resonance phenomenon, which arises from the collective oscillation of conduction electrons in response to incident light, provides a reliable optical signature for confirming nanoparticle formation and offers insights into particle size, shape, and aggregation state. Because the phytochemicals present in plant extracts contain functional groups including hydroxyl, carboxyl, and carbonyl moieties, this interaction with metal ions serves dual functions, with these biomolecules acting as both the reducing agents that convert metal ions to elemental nanoparticles and as the capping agents that stabilize the resulting nanoparticles and prevent uncontrolled aggregation. The presence of these functional groups on the nanoparticle surface is critically important because they determine the surface chemistry, charge, and reactivity of the nanoparticles, which in turn influence their interactions with biological systems and their performance in various applications. Present literature has identified similar types of maximum absorbance peaks across numerous studies employing different plant species for nanoparticle synthesis, giving a connection to the previous findings and validating the reproducibility of green synthesis approaches while also highlighting the diversity of plant sources that can be successfully utilized for this purpose.

While specific studies on zinc nanoparticles synthesized using Suaeda monoica are scarce in the existing scientific literature, the plant's known antioxidant and antimicrobial properties indicate potential biological activity that could be harnessed for nanoparticle synthesis and therapeutic applications. Previous phytochemical investigations have demonstrated that methanolic extracts of S. monoica possess strong antioxidant activity in DPPH radical scavenging assays and exhibit significant antimicrobial effects against various test microorganisms. This study suggests that the phytochemical constituents of S. monoica, including flavonoids, phenolic compounds, alkaloids, and other secondary metabolites, may serve a dual function in the context of nanotechnology by assisting in the reduction and stabilization of nanoparticles during synthesis and subsequently contributing to their bioactivity through synergistic interactions with the metal core (2). The concept of dual functionality is particularly attractive for biomedical applications, as it implies that the biological activity of the nanoparticles may be enhanced beyond what would be expected from the metal alone, potentially yielding formulations with improved efficacy for therapeutic uses.

Similarly in a previous investigation, zinc oxide nanoparticles were biosynthesized using the root bark extract of Cassia sieberiana and subsequently evaluated for various biological activities. The resulting nanoparticles exhibited excellent anti-inflammatory responses in standard assay systems, along with significant antioxidant and antimicrobial properties. Characterization studies revealed the formation of spherical nanoparticles with an average size of approximately 12.9 ± 3.1 nm, and the observed colloidal stability likely contributed to the consistent biological effects observed across multiple assays (4). The relationship between nanoparticle size, stability, and biological activity is a recurring theme in nanomedicine research, with smaller, more stable nanoparticles generally demonstrating enhanced cellular uptake, more favorable biodistribution, and greater apparent biological activity compared to larger, aggregated particles.

Similar patterns have been reported for zinc oxide nanoparticles synthesized from other botanical sources, supporting the generalizability of green synthesis approaches and the consistency of their biological effects. Green ZnO nanoparticles prepared using Sargassum seaweed extracts showed significant inhibition of protein denaturation across a range of test concentrations, with the anti-inflammatory effects being attributed to phenolic compounds present on the nanoparticle surface that enhance interaction with albumin and other proteins to reduce inflammatory responses (Lopez-Miranda et al. 2023). The presence of surface-associated phytochemicals is a distinguishing feature of green-synthesized nanoparticles compared to those produced by chemical methods, and this biological coating may confer advantages for biomedical applications by improving biocompatibility, enhancing target interactions, and providing additional therapeutic benefits beyond those of the metal core.

Comparative studies using plant extracts such as Catharanthus roseus have also demonstrated robust anti-inflammatory effects of green zinc oxide nanoparticles, with inhibition values ranging between approximately 48% and 89% depending on the concentration tested (Nag 2009). These results substantiate the consistent trend seen in the current study, suggesting that green synthesis not only facilitates environmentally friendly nanoparticle production but also confers enhanced biological efficacy due to the presence of plant phytochemicals acting as reducing and capping agents that remain associated with the nanoparticle surface throughout the synthesis and purification process. The consistency of findings across multiple plant species and research groups strengthens the evidence base for green synthesis as a viable approach to producing therapeutically active nanomaterials.

A proposed mechanism for the anti-inflammatory activity of plant-derived zinc nanoparticles involves the modulation of inflammatory pathways at multiple levels, including inhibition of protein denaturation which prevents the formation of immunogenic protein aggregates, and stabilization of cellular membranes which prevents the release of pro-inflammatory mediators from activated immune cells. The phytochemicals derived from Suaeda monoica—including flavonoids, phenolic acids, and antioxidant compounds—likely contributed to the observed anti-inflammatory activity by synergizing with the zinc ions and nanoparticles, similar to mechanisms reported in other studies where higher phenolic content in plant extracts correlated with stronger inhibition of inflammatory responses. This synergy between the metal nanoparticles and the phytochemical coating represents a unique advantage of green synthesis approaches and may enable the development of combination therapies that address inflammatory conditions through multiple mechanisms simultaneously.

The antibacterial activity of S. monoica was investigated in previous studies, and the results confirmed that bioactive secondary metabolites were produced by this halophytic species, contributing to its traditional medicinal uses and justifying further exploration for pharmaceutical applications. S. monoica has been shown to contain a variety of bioactive substances with vast possibilities for antibacterial action against a range of disease-causing microorganisms, and these natural products offer the additional advantage of functioning without the negative side effects often associated with synthetic antimicrobial agents. These findings support the possibility of using the chosen plant extract not only for nanoparticle synthesis but also as a bioactive agent in its own right, with direct antibacterial activity that could complement or enhance the effects of the nanoparticles themselves. S. monoica demonstrated potent antibacterial activity against the three oral pathogenic bacterial strains included in the study, specifically Streptococcus mutans, Staphylococcus aureus, and Klebsiella species, indicating broad-spectrum antimicrobial potential relevant to oral health and beyond. As per the present investigation, the zone of inhibition was examined for each bacterial strain and compared with the control antibiotic Tetracycline, providing a reference point for evaluating the relative efficacy of the plant extract. The extract affected all tested bacteria to varying degrees, demonstrating that the bioactive compounds present in S. monoica are active against both Gram-positive and Gram-negative organisms. Streptococcus mutans, however, demonstrated the most pronounced antibacterial action among the tested strains, which is particularly significant given the central role of this organism in dental caries pathogenesis. The high concentration of phenols and flavonoids present in the leaf extract, as determined through phytochemical analysis, indicates that these chemicals may have a significant role in both the antioxidant and antibacterial activities observed, consistent with the well-documented biological properties of these compound classes (5-8). The correlation between phenolic content and biological activity observed in this study aligns with the broader literature on plant-derived antimicrobials and supports the continued investigation of S. monoica as a source of bioactive compounds for pharmaceutical and nanotechnological applications.

CONCLUSION:

The present effective and environmentally friendly method was inspired by the anti-inflammatory properties of S. monoica, which may find potential use in dental care products. It has been demonstrated that S. monoica extracts exhibit antibacterial activity against MRSA, Klebsiella species, and Streptococcus mutans. This has sparked conjecture about the extract's possible function in preventing the emergence of antibiotic resistance. The results of the experiment also lend credence to the prospect of using S.monoica as an oral care agent when it is examined for clinical use.

LIMITATIONS:

The investigation was carried out in an in vitro setting with few test samples. Therefore, it's possible that the anti-inflammatory efficacy data by themselves are insufficient to demonstrate its therapeutic efficacy. Future study will focus on determining the precise mechanism of action of these NPs against different infections through ex vivo studies and clinical trials.

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