RESEARCH PAPER

Constructing Silver Nanoparticles using Various Seaweed Retrieves and Exploring Their Antimicrobial and Anticancer Properties

[1]Vanakkam. S, [2*]Ajith Sinthuja. S, [3]Gladis Latha. R, [4]Sudha Kumari. S.

[1]Research Scholar, Holy Cross College (Autonomous), Affiliated to Manonmaniam Sundaranar University, Tirunelveli- 627 012, Tamilnadu, India, https://orcid.org/0000-0002-4467-3253

*[2]*Assistant Professor, Department of Chemistry, Holy Cross College (Autonomous), Nagercoil, Kanyakumari-629004, Tamil Nadu, India.*

[3]Assistant Professor of Chemistry, Holy Cross College, Nagercoil, Kanyakumari-629004, Tamil Nadu, India.

[4]Assistant Professor of Chemistry, S.T. Hindu College, Nagercoil, Kanyakumari-629002, Tamil Nadu, India.

***Email id: sasinthuja.hcc@gmail.com**

Paper received:11-06-2026 Accepted: 23-07-2026 Published:21-08-2026

Abstract

In contrast to conventional biologic approaches, the fabrication of metal nanoparticles using seaweed offers greater its biocompatibility and is a novel and mostly unexplored strategy. This innovative technique harnesses algae extract for rapid and non-toxic production of metal nanoparticles, resulting in particles that are ideally sized to unlock remarkable potential for a wide array of biomedical applications. The microbiological and cancerous properties of silver nanoparticles, AgNP-Tc/To, which are made along a mixture of two brown seaweeds, Turbinaria Conoides (Tc) and Turbinaria ornate (To), that are gathered near India's coastal areas, are examined in this work. Multiple techniques for analysis were used to characterize the produced silver nanoparticles. The bacterial strains subjected to testing were those exhibiting multidrug resistance, a growing concern attributed to the indiscriminate use of antimicrobial agents in clinical settings, fostering resistance patterns. According to the findings, the most potent antibacterial action against Escherichia coli (EC), Klebsiella pneumonia (KP), Bacillus cereus (BC), Staphylococcus aureus (SA), and Bacillus subtilis (BS) was shown by 10 µg/mL of AgNP-(Tc/To). This was quantitatively assessed through the measurement of the zones of inhibition. Furthermore, when exploring the interplay between dietary antioxidants and oxidative stress related pathologies, the assessment of total antioxidant activity serves as a critical parameter. Green mixed synthesized silver nanoparticle AgNP-Tc/To, effectively kill $HepG_2$ cancer cells in a dose-dependent manner. The viability of cells decreases to 5.47% as dosages vary from 10.3 µg/mL to 23 µg/mL, while the cytotoxicity rises from 10 µg/mL to 100 µg/mL. The nanoparticle has IC_{50} value of 33.18 µg/mL. Silver ions released from AgNP-Tc/To interact with cancer cell enzymes and damage nucleic acids, leading to chromosomal defects.

Keywords: Silver Nps, Mixed Seaweeds, bioreserves, bioactive, antibacterial and antioxidants

How to cite this article: 1Vanakkam. S 2*Ajith Sinthuja. S 3Gladis Latha. R 4Sudha Kumari. S.. Constructing Silver Nanoparticles using Various Seaweed Retrieves and Exploring Their Antimicrobial and Anticancer Properties. Int J Drug Deliv Technol. 2026;16(78s):1249-1258. DOI: 10.25258/ijddt.16.78s.135.

1. Introduction

Because of their high surface-to-volume ratios, nanoparticles perform exceptionally well, especially when they are manufactured with at least one dimension that is between 1 and 100 nm. Because of their improved surface area-to-volume ratio and unique physical, biological [1], and chemical [2] features, their special qualities differ greatly from those of traditional materials. Although there are many different chemical and physical synthesis techniques, they can be unaffordable and frequently employ hazardous chemicals and organic solvents [3], which can have negative effects on the environment and human health [4]. As a result, biologically mediated nanoparticle manufacturing has become a viable substitute [5], providing a more economical and environmentally responsible approach that reduces risks to human health [6]. Scientists have begun to utilize biological substances including fungi, bacteria, whole plants, along with natural products to generate and stabilize nanoparticles using non-toxic approaches. Currently, the market has seen the development of over 800 innovative products leveraging nanotechnology [7], with demand for further advancements continuing to rise [8].

Recent advancements in environmentally benign nanoparticles aimed at enhancing human well-being can be attributed to significant strides in nanotechnology [9-10], driven by interdisciplinary scientific contributions [11-12]. The conventional synthesis methods for gold and analogous nanoparticles predominantly rely on physical and chemical approaches, which are often accompanied by several limitations [13]. These include the necessity for hazardous chemicals, elevated temperatures, low pH environments, costly equipment, and laborious, low-yield procedures [14]. Consequently, there has been a growing impetus within the biomedical sector to explore more sustainable and cost-effective alternatives. Bio-fabrication of nanomaterials has emerged as a promising avenue, revealing that natural resources offer superior alternatives for nanoparticle synthesis [15]. Pioneering researchers in this field have predominantly focused on microorganisms due to their extensive diversity and potential as repositories of bioactive compounds [16]. A quick and efficient way to create new nanomaterials is to use fungi and bacteria for the green production of nanoparticles [17]. Among the various biological resources, marine algae stand out as a rich source with wide-ranging applications. Especially notable is macroalgae, or seaweed, which serves as a critical marine resource for extracting medicinal compounds. Isolated bioactive compounds from macroalgae, particularly from brown seaweeds, are associated with diverse biological activities, including antibacterial [18], anticoagulant [19], and antifouling [20] properties. Algae have been extensively utilized for centuries and hold a special place in maritime nations' traditional medical practices as vermifuges, cosmetics, and antimicrobial agents for the treatment of a wide range of illnesses, including carcinoma, arthritis, a tumor sneeze infections, high blood pressure, and genital disorders [21–23]. The brown algae T. conoides and T. ornate belong to the Sargassaceae family as well as category Fucales. Its constituents include a significant amount of steroids, several fucosterol, various molecules with vinyl and methyl fatty acids varieties, cyclohexane [24], and a few soluble polysaccharides like fucoidan, a neutral party glucan, which and remains of guluronic along with mannuronic acid. that contain alginic acid, rhamnose, sugars, the sugar arabinose xylose and the sugar mannose, fructose, insulin, and uronic acidic substances, giving the brown algae its curative properties [25–26].

Bacterial infections continue to be a leading cause of mortality globally, despite the availability of various antibiotics and antimicrobial treatments. Given the escalating concern regarding multidrug-resistant bacterial strains, it is crucial to develop medications with robust antibacterial properties. The increasing prevalence of microbial diseases, coupled with rapid bacterial mutations and the swift emergence of resistance to existing antibiotics, underscores the need to discover or modify substances that demonstrate antibacterial activity, in conjunction with other therapeutic approaches [27]. Recent advancements in nanotechnology have facilitated the development of nanoscale materials that possess potent antibacterial effects against multidrug-resistant pathogens; therefore, these materials may provide an excellent foundation for addressing bacterial evolution. Up until now, marine algae have produced Ag and Au nanoparticles with an emphasis on their antibacterial capabilities against a variety of diseases. Future research is therefore required to verify that the physiochemical characteristics of the Ag and Au nanoparticles produced by marine algae are comparable to those produced by more traditional methods of fabrication and are capable of being applied to different fields [28]. This is especially significant because traditionally produced Au nanoparticles have been employed in a number of medicinal purposes, including as focuses in malignancies for thermal treatment regimens, biological sensors, and transmitters for drugs against cancer [29]. However, this subject area is still mostly unexplored, and only a small number of marine plants as well as algae are being investigated to yet. For the synthesis of metal and metallic oxide nanoparticles, there are therefore exceptional prospects for research and the development of novel biogenic technologies based on sustainable chemistry.

Additionally, the production of Au nanoparticles utilizing the marine alga called Sargassum wightii Greville has been documented [30]. The alga quickly generated stable, spherically shaped nanoparticles in their study, with sizes ranging from 8 to 15 nm. The marine alga Tetraselmis kochinensis was used to explore the process of biosynthesis of Au nanoparticles [33], whereas other researchers managed to generated a broad variety of secure nanoparticle that passes nano dimensions [31]. According to the analysis, the crystallized nanomaterials were mainly cylindrical in shape with trace amounts of hexagonal and triangular platelets, and their dimensions fluctuated between 18.7 to 93.7 nm. Additionally, the study discovered that Au reduction was directly influenced by the hydroxyl groups of the di-terpenoids contained in brown seaweed.

The two types of brown seaweeds Turbinaria conoides with Turbinaria ornate were used in the present research to explore the ecologically sound creation of silver nanoparticles. Certain algae from the sea were chosen because of very abundant phytochemical makeup, which aids in stabilizing nanoparticles and reducing silver ions. The produced silver nanoparticles were then examined by employing sophisticated analytical methods, such as scanning electron microscopy, or SEM, for analyzing their dimensions and forms, XRD (X- Ray Diffraction) for crystallographic assessment, and the use of Fourier transform infrared spectroscopy (FT-IR) to determine their functional components. Additionally, the generated silver nanoparticles' antibacterial activity was thoroughly examined against a variety of harmful bacteria, namely the Pseudomonas aeruginosa Escherichia coli, and bacteria like Bacillus subtilis, and Staphylococcus aureus. The outcomes highlighted the use for such biogenically produced nanoparticles in both the biopharmaceutical and health care industries by demonstrating their ability to serve as strong antibacterial agents.

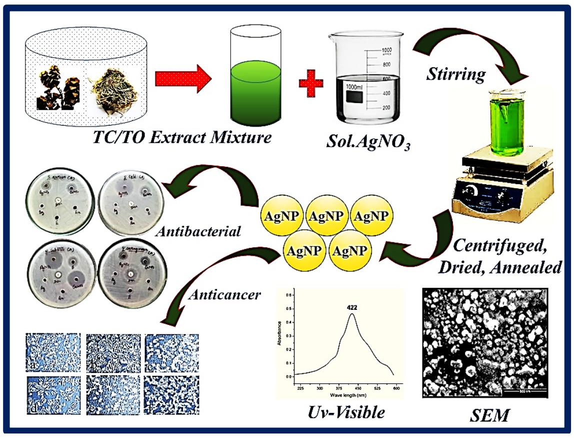

Figure 1. Scheme of synthesizing AgNP-Tc/To from seaweeds mixture

2. Materials and methods

2.1 Essential Materials

Water extract was made from brown seaweed called *Turbinaria Conoides* and *Turbinaria ornate* which was gathered in south Indian coastal areas. Merck specialities Private Limited, Mumbai was contacted to order silver nitrate ($AgNO_3$). As a solvent, double-distilled, ionised water was utilised in the synthesis. Before being used, each and every piece of glassware has been cleaned with distilled water and dried in the oven.

2.2. Procedure Adapted

2.2.1 Preparation of *Turbinaria Conoides* and *Turbinaria ornate* extract

Using distilled water, the dehydrated seaweeds of Turbinaria Conoides and Turbinaria ornate species cleaned to remove harmful materials. To make the marine algae extraction used in the production, 5 grams of each meticulously cleaned algae were put in a 500 milliliter Erlenmeyer vessel and boiled in 100 milliliters of the water that was double-distilled for 15 minutes. The processed algal extracts were stored for subsequent usage at -15 degrees Celsius as well as retained its useable for several weeks.

2.2.2 Green production of nanoparticles of silver. Green silver nanoparticles were synthesized using aqueous suspension of silver nitrate (1.5 mM) made with double-distilled water. For reduction into Ag^+ ions, 20 ml of Turbinaria Conoides and Turbinaria ornate seaweed extract (20 ml + 20 ml, 10%) was added to 40 ml of 1.5 mM silver nitrate. Using a magnetic stirrer, the mixture was heated while being vigorously stirred for two hours. The color shift of the reaction compositions from a greenish yellow to bright orange was frequently observed. Additionally, AgNps were found in solution by searching for absorption peaks at about 360 and 445 nm. The creation of AgNPs is confirmed by the presence of an intense absorbance. The resultant mixture was centrifuged at 3800 rpm to separate the generated nanoparticle. To get rid of moisture and low volatile contaminants, the isolated nanoparticle was cleaned with water and dried at 100 degrees Celsius. The dry specimen was then heated for three hours at 310–350 oC in a muffle oven. The dehydrated powder was kept for later examination.

2.2.3. Analytical Methods. Using a Deep Vision UV-visible spectrophotometer, a thorough UV-visible analysis of the production of silver nanoparticles was carried out over a wavelength range of 200 to 900 nm. In the 4000–400 cm-1 range, the FT-IR spectra of TC/TO AgNPs were obtained using a PerkinElmer FTIR spectrophotometer and the KBr pellet methodology. To characterize the crystalline structure of the silver nanoparticles, a diffractometer with X-rays (D8 Advance ECO) was operated at 40 kV and 30 mA using Cu Kα1 radiation in a θ–2θ configurations. The overall length of the XRD peaks was measured using the Debye-Scherrer formula to assess the crystallinity of the silver nanoparticles. The generated TC/TO AgNPs' morphology was examined using both scanning electron microscopy (EVO18 by CARL ZEISS) and transmission electron microscopy (Tecnai).

2.2.4. Antibacterial Activity.

The agar well diffusion method was used to assess the nanoparticles' antibacterial effectiveness. An overnight culture of Escherichia coli (EC), Klebsiella pneumonia (KP), Bacillus cereus (BC), Staphylococcus aureus (SA), and Bacillus subtilis (BS) was inoculated into nutrient agar plates with 15 ml of solidified media using a 100 µl aliquot. Wells with a diameter of 7 mm were made in the agar after inoculation. Following that, both the standard and nanoparticle samples were put into these wells. For a whole day, the plates were incubated at 37 °C. The widths of the inhibition zones were measured in millimeters to evaluate the antibacterial activity following incubation.

2.2.5. Anticancer activity

HepG2 cells were used to test anticancer activities in the lab. Folate-free Dulbecco Modified Eagle's Medium (FFDMEM) with a concentration of 10% fetal bovine serum (FBS) and antibiotics was used to cultivate these cells at 37°C with 5% CO2. The MTT assay, in which living cells transform a yellow substance known as MTT into a purple formazan, was used to gauge cell viability. Using HepG2 cells from the National Center for Cell Sciences (NCCS) in Pune, we assessed the toxicity of several chemicals. Using 1 mL of a medium containing RPMI per well, we plated 1 × 105 cells in 24-well plates and allowed them to germinate for 48 hours. After adding test samples in different quantities, we cultured for an additional day at 37°C. After incubation, we washed the cells with PBS, added 200 µL of a 0.5% MTT-PBS solution, and incubated for 4 hours. Next, we added a solution of 0.04 M HCl/isopropanol and measured the purple formazan dye using a microplate reader at 570 nm. We estimated the concentration needed to inhibit 50% of cell viability (IC_{50}) and expressed the effect of the samples as a percentage of cell viability.

3. Results and Discussion

In recent years, the science of environmentally friendly nanotechnology has employed a variety of kinds of seaweed as reducing agents to produce nano-metals. The researchers used a blend of brown algae comprising Turbinaria Conoides as well as Turbinaria ornate that could effectively biosynthesize silver nanoparticles having a conventional diameter of 16.51 nanometers.

3.1 FTIR Spectrum of TC/TO-AgNPs

When employing marine algae for the manufacture of metal nanoparticles, the silver nanoparticle of AgNp-Tc/To (Figure 2) exhibits absence of peaks throughout the amide bonding I and amide bonding II regions typical of proteins/enzymes that were recently discovered to be in charge of reducing the concentration of metal ions in the body. The peak values which were seen are more typical of the terpenoids and flavanones that are found in large quantities in seaweeds. The probable existence of the two compounds. or terpenoids are molecules consumed upon the outermost portion of silver nanoparticles is suggested by the presence of several peaks at 3407 (stretching out O-H bonds), 1770 (lengthening C=O bonds), 1630 (C=C or chemically aromatic classes), 1384 (geminal methyls), 1539 (C-C), and 917 alongside 863 (the bending vibrations of –O-H group). The outermost layer of metallic nanoparticles might absorb flavanones or terpenoids, perhaps involving contact with carbonyl groups or π-electrons if there are no other potent ligating agents present in high enough concentration. The C–O stretching mode of esters/ether is represented by the peaks between 1330 and 1022 cm–1.

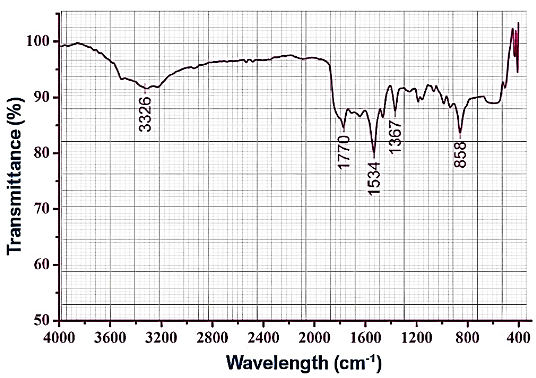

Figure 2. FTIR spectrum of AgNp-Tc/To

3.2 UV – Visible study of AgNp-Tc/To. Surface plasmon resonance (SPR) is liable for the brown hue that is produced during the production of silver nanoparticles.

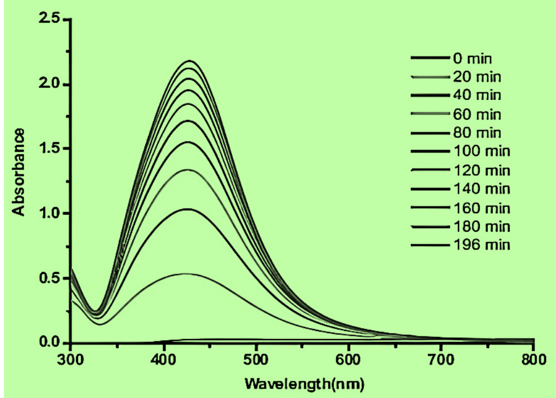

Figure 3. Uv-Visible spectrum of AgNp-Tc/To

It has been found that SPR for AgNP-Tc/To raise around 422 nm as the response time increased and then stopped at 196 min. It has been found that silver ion can be reduced to Ag metal with the formation of their equivalent nanoparticles by *Turbinaria Conoides* and *Turbinaria ornate* seaweed extract through the secondary metabolites binding with Ag binding groups. Thus, diluted solutions were more favourable for AgNP-Tc formation, as seen by the progressive acute plasmon resonance peak (Figure 3).

3.3. Characterization of silver nanoparticles using XRD

Bragg's reflection was used to identify peaks in the AgNp-Tc/To XRD spectrum that corresponded to the faces-centered cubic (FCC) crystalline structure's (111), (200), (220), as well as (311) surfaces (Figure 4). These peaks showed 2θ values between 32.26 & 46.22, which are consistent with those found in JCPDS No. 04-0783 acceptable levels for silver. The characterization of the produced AgNPs as nanocrystals was substantiated by comparing their XRD spectra with the standard values. In addition to the conventional Bragg's peak indicative of FCC AgNPs, other peaks were detected, suggesting that the surface of the AgNPs underwent crystallization involving bioorganic phases or phytoconstituents. The silver nanoparticles made from the seaweed extract thus actively decreased Ag+ ions, as the XRD pattern demonstrates. Moreover, the little changes in peak positions suggested the existence of strain in the crystal structure. As a result, the detection of Ag nanocrystals in the XRD pattern supports the conclusions drawn from the SEM and UV-Vis spectra.

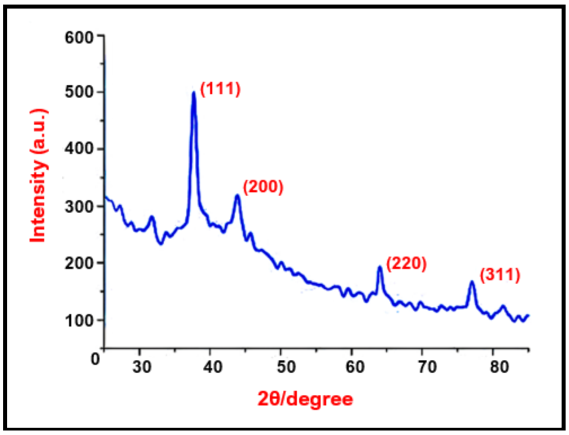

Figure 4. XRD of the AgNp-Tc/To synthesized from seaweed extract mixture

3.4. SEM analysis of AgNp-Tc/To

The scanning electron microscope (SEM) was utilized for an in-depth morphological analysis of the synthesized silver nanoparticles. To carefully assess the size distribution and structural characteristics of the nanoparticles created during the manufacturing procedure, the green generated AgNp-Tc/To was subjected to SEM imaging. The bulk of the particles were found to be between 27 and 64 nm in size, as shown in Figure 5, which is suggestive of successful nanoparticle manufacturing. Upon closer inspection, it was noted that the larger nanoparticles exhibited a distinctive surface morphology, characterized by a coating of smaller nanoparticles. This phenomenon suggests potential agglomeration or layered formation during the synthesis. Additionally, although a diversity of particle types was present in the samples, the predominant morphology observed was spherical, which is often desirable for certain applications due to enhanced stability and uniformity. The variances in particle shape and size observed in the SEM images hint at potential correlations that could reflect the underlying synthesis conditions and mechanisms. These results open the door for more research into how these morphological traits affect the physical and chemical qualities of silver nanoparticles, which are essential for their use in industries like electronics, medicine, and catalysis.

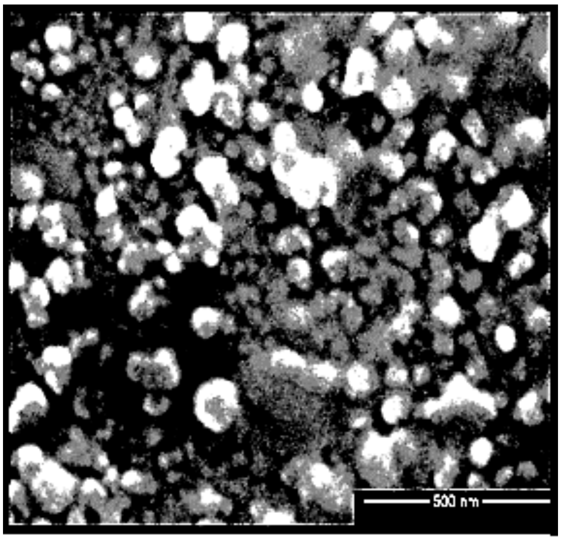

Figure 5. SEM micrograph of the AgNp-Tc/To synthesized from seaweed extract mixture

3.5. TEM analysis of AgNp-Tc/To

The images obtained through high-resolution electron microscopy demonstrated a uniform distribution of nanoparticles across the observed samples. A detailed analysis of the micrographs presented in Figure 6 revealed that the particle size varied between approximately 42 to 50 nanometres (Figure 6). This specific size distribution is predominantly comprised of spherical silver nanoparticles, which possess distinct properties inherent to elemental silver (Ag). Silver has a finely segmented structure with high surface area-to-volume ratios at the nanoscale, which results in improved reactivity and distinctive optical effects. For applications like catalysis, electronics, and biological usage, where their characteristics can greatly affect the overall performance and efficacy of the materials, these nanoparticles' morphological homogeneity and regulated size range are essential.

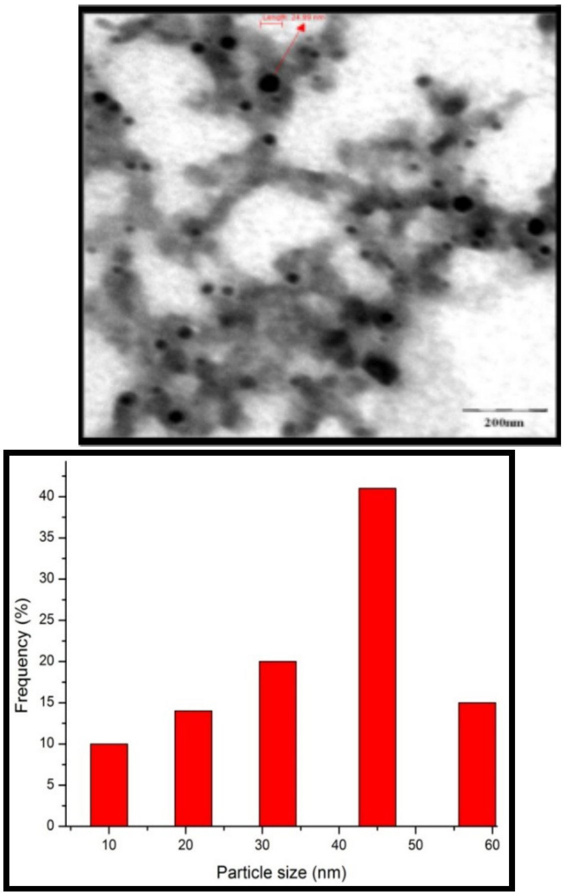

Figure 6. TEM micrograph of AgNp-Tc/To and the particle size distribution

3.6. Antibacterial activity of AgNp-Tc/To

Figure 7 shows how silver nanoparticles, in particular AgNp-Tc/To, exhibit outstanding antibacterial properties against a variety of bacterial pathogens, including Pseudomonas aeruginosa, E. coli, Bacillus subtilis, Staphylococcus aureus, Bacillus cereus, and Klebsiella pneumoniae. In this investigation, these pathogens were treated with varying quantities of silver nanoparticles, and the results showed that the inhibitory effects grew stronger with increasing concentrations. Table 1 displays the radial radii of the inhibition zones for the chosen bacterial strains, demonstrating the potential of AgNp-Tc/To even at a 10 µg/ml concentration.

Table 1 Zone of Inhibition of AgNp-Tc/To against selected bacterial strains

Bacteria	Control	AgNp-Tc/To (mm)
***Klebsiella pneumoniae* (KP)**	21	23
E. coli	13	18
***Bacillus subtilis* (BS)**	18	24
***Staphylococcus aureus* (SA)**	16	25
***Bacillus cereus* (BC)**	20	28
***Pseudomonas aeruginosa* (PA)**	24	19

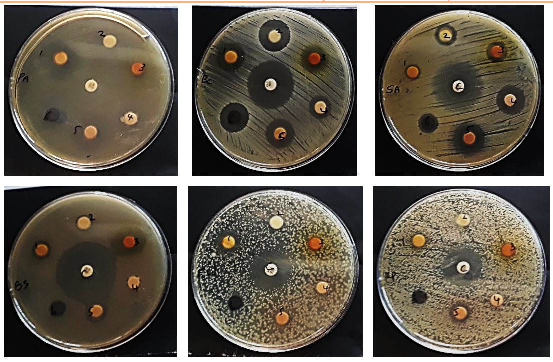

Figure 7. Zone of Inhibition of AgNp-Tc/To against Pseudomonas aeruginosa (PA), Bacillus cereus (BC), Staphylococcus albus (SA), Bacillus subtilis (BS), Pseudomonas aeruginosa (PA), Klebsiella pneumoniae (KP)

The significant antimicrobial effects arise from the impressive high surface area-to-volume ratio of the silver nanoparticles, enabling profound interactions with pathogens. The appropriately sized nanoparticles bind to microorganisms effectively, with electrostatic attraction between the relatively neutral AgNp-Tc/To and the negatively charged microbial cell membranes facilitating their entry. Once inside, AgNp-Tc/To transforms the membrane architecture and depletes ATP by disrupting respiratory functions, leading to cell death. These findings illuminate the highly selective antibacterial activities of silver nanoparticles, demonstrating their greater sensitivity and efficacy against gram-positive bacteria compared to gram-negative bacteria [34].

3.7. In-vitro anticancer activity of AgNp-Tc/To

The green-synthesized silver nanoparticles, referred to as AgNP-Tc-To, are demonstrating significant potential in the fight against HepG2 cancer cells, showcasing impressive cytotoxic effects through a well-defined direct concentration-dependent methodology. Recent studies indicate that the cytotoxicity of AgNP-Tc-To progressively escalates as concentrations increase from 10 µg/mL to 100 µg/mL (Figure 8). At this elevated concentration threshold, the viability of HepG2 cancer cells plummets to a striking 5.47%, highlighting the nanoparticles' remarkable efficacy in inhibiting cancer cell survival. The anticancer properties of the synthesized AgNP-Tc-To nanoparticles are noteworthy, with IC50 values calculated at 33.18, 54.95, and 66.58 µg/mL, showcasing their potency in challenging cancerous growth. Despite these promising results, the intricate mechanisms by which these silver nanoparticles exert their anticancer effects remain incompletely elucidated. It has been established that silver ions are mobilized from the AgNP-Tc-To, penetrating the cancer cell environment, where they instigate substantial interactions with the membrane-associated enzymes of these malignant cells. Additionally, these silver ions have a significant impact on vital biomolecules within the cells, particularly targeting nucleic acids such as DNA and RNA, which leads to consequential damage and may induce chromosomal anomalies. This multifaceted interaction suggests a complex and potent mechanism by which AgNP-Tc-To nanoparticles may hinder cancer cell proliferation and instigate cellular apoptosis, ultimately contributing to their role as innovative therapeutic agents in oncology [35].

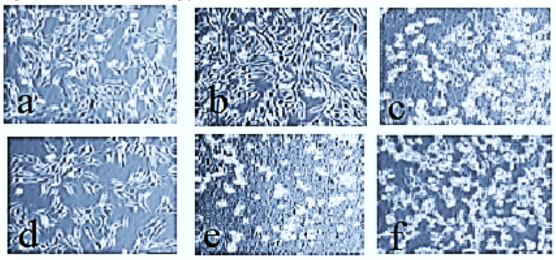

Figure 8. Bio-synthesized AgNP-Tc-To anticancer assay at varying concentrations: (a) Control, (b) 10 µg/mL, (c) 25 µg/mL, (d) 50 µg/mL, (e) 75 µg/mL, and (f) 100 µg/mL.

4. Summary

Smaller in size and possessing exceptional nanostructures, the biologically produced AgNPs show promise as materials that prevent bacteria from forming marine biofilms and are highly effective in killing brine shrimp, specifically Artemia salina.In order to stop fouling consortia from settling and growing, the current study proposes that clean, nontoxic, and environmentally acceptable nanoparticles that have been biologically synthesized can be used as coating materials on the surfaces of aquaculture installations and other marine systems. Furthermore, to confirm the benefits of the produced Ag NPs, in vivo research on these novel antifouling techniques is required. Proteins or enzymes that are involved in reducing metal ions with seaweeds do not exhibit peaks in the FT-IR analysis of AgNp-Tc/To. Rather, it emphasizes terpenoids and flavanones that are prevalent in seaweeds, suggesting that these substances might adhere to the surface of the nanoparticle. Esters and ethers' C–O stretching is reflected in the peaks between 1330 and 1022 cm–1. Silver nanoparticles' brown hue is caused by surface plasmon resonance, or SPR. The synthesis of silver nanoparticles using extracts from Turbinaria Conoides and Turbinaria ornate seaweed is confirmed by the SPR for AgNP-Tc/To, which peaked at approximately 422 nm. With 2θ values of 32.26 and 46.22, the AgNp-Tc/To XRD spectrum had peaks that matched the face-centered cubic (FCC) structure, indicating the existence of nanocrystals. Crystallization with bioorganic phases is suggested by additional peaks. Shifts in peak positions show strain in the crystal structure, and this supports the reduction of Ag+ ions. We examined silver nanoparticles produced by green synthesis using a scanning electron microscope (SEM). The majority of the particles were spherical and ranged in size from 27 to 64 nanometers. High-resolution TEM images showed a consistent distribution, with sizes between 42 and 50 nanometers. Silver nanoparticles, particularly AgNp-Tc/To, are effective against several bacteria, including Klebsiella pneumoniae and E. coli. Testing revealed that higher concentrations enhance their antibacterial effects even at 0.1 mg/ml. Their efficacy comes from a large surface area that allows strong interactions with bacteria. The nanoparticles attach to negatively charged bacteria and disrupt their membranes, leading to cell death. These findings show stronger effects against gram-positive bacteria. In addition, the green-synthesized AgNP-Tc-To nanoparticles show promise against HepG2 cancer cells. Their toxicity increases with concentration, dropping cell viability to 5.47 % at 10.3 to 23.0 µg/mL, indicating their power in fighting cancer. Their IC50 values are 33.18, 54.95, and 66.58 µg/mL. However, the exact mechanisms remain unclear. Silver ions released from AgNP-Tc-To enter cancer cells and affect essential enzymes and DNA, causing damage that may lead to cell death. This suggests that AgNP-Tc-To could be new potential treatments for cancer.

5. Future scope

The biogenic synthesis of nanoparticles through nano-biotechnology presents a compelling avenue for more sustainable manufacturing practices, significantly reducing environmental pollution and mitigating health risks associated with hazardous chemicals. The production of metal and metal oxide nanoparticles depends heavily on marine environments, which are rich in renewable resources like seaweed and seagrass. With a focus on gold and silver nanoparticles, which are known for their strong antibacterial qualities, recent studies highlight the therapeutic potential of nanoparticles in pharmaceuticals. Because of their biocompatibility and ease of functionalization, gold nanoparticles in particular are being investigated for a number of medical uses, such as targeted drug delivery and cancer therapy. Additionally, they are essential to diagnostics, especially in imaging and biosensing technology. The special magnetic characteristics of iron oxide nanoparticles, or Fe3O4, set them apart and make them ideal for uses like targeted drug delivery systems and magnetic resonance imaging (MRI) [36]. But there is still a dearth of scientific research on their synthesis from marine algae, indicating a promising field. Nanoparticles of copper oxide and zinc oxide are both receiving more attention due to their important applications in catalysis and medicine. While copper oxide nanoparticles have potent antimicrobial activity that makes them useful in disinfectants and as catalysts in chemical reactions, zinc oxide nanoparticles have anti-inflammatory and antimicrobial qualities that make them good candidates for wound healing and as drug delivery vehicles. Future research endeavors should delve deeper into the multifaceted potential of these nanoparticles, particularly focusing on their applications in cancer therapeutics and the development of advanced biosensors. Furthermore, the study calls for a more comprehensive investigation into the bioactive compounds found in brown algae, examining their implications in programmed cell death pathways and the broader spectrum of potential medical applications they may offer. Enhanced biological compatibility in medicinal products and novel treatments may result from this study's findings.

6. Conclusion

In this investigation, we utilized the brown seaweed species Turbinaria conoides and Turbinaria ornate as reducing and stabilizing agents. This approach enabled us to develop a sustainable process for manufacturing silver nanoparticles (AgNp-Tc/To). The spherical form and face-centered cubic (FCC) structure of the nanoparticles made using this technique were among its noteworthy features. The greenly produced silver nanoparticles appeared primarily spherical, with diameters that varied between 27 to 64 nanometers, according to scanner electron microscopy (SEM) research. Images from TEM, or transmission electron microscopy, showed diameters ranging from 42 to 50 nanometers in length According to the findings, the most potent antibacterial action against Escherichia coli (EC), Klebsiella pneumonia (KP), Bacillus cereus (BC), Staphylococcus aureus (SA), and Bacillus subtilis (BS) was shown by 10 μg/mL of AgNP-(Tc/To). Their concentration-dependent toxicity reduced cell viability to 5.47 % when concentrations rise from 10.3 μg/mL to 23 μg/mL, with an IC50 value of approximately 33.18 μg/mL against HepG2 cancer cells. While the precise mechanisms of action are not fully understood, the release of silver ions may damage DNA and essential enzymes in cancer cells, suggesting the potential use of AgNP-Tc-To as a cancer treatment. The implications of this study extend beyond fundamental research; our findings could serve as a foundation for future investigations into innovative Nanomedicine. Additionally, our synthesized nanoparticles may be used as templates for the targeted delivery of algal-based medicines, which could significantly enhance the efficacy of treatments against severe infections and lead to new therapeutic approaches in medicine.

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