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A Novel Green Biosynthesis Approach and Structural Characterization of Ag–Fe Bimetallic Nanoparticles using the Red Alga Galaxaura rugosa

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Abstract

A Novel green and eco-friendly approach has been used to biosynthesize Ag-Fe bimetallic nanoparticles (Ag-FeBNPs), mediated by an aqueous extract of the red alga species; *Galaxaura rugosa.* The surface plasmon resonance band is positioned at 264 nm for Ag-FeBNPs. X-ray diffraction analysis (XRD) illustrated the crystalline nature of biogenic nanoparticles. Transmission electron microscopy (TEM) and selected area electron diffraction (SAED) showed that the particles have a crystalline spherical shape with a size range from 14.3 to 22.1 nm. Scanning electron microscopy (SEM) and Energy dispersive analysis (EDAX) give the surface morphology and elemental composition of Ag-FeBNPs which is spherical in high intensity. Fourier transmittance infrared spectroscopy (FTIR) showed that the biomolecules are responsible for forming and stabilizing Ag-FeBNPs. Zeta potential values show − 15.7 mV. The findings of this study documented the great potentiality of Ag-FeBNPs that would significantly impact the field of nanobiotechnology and nanoscience in the future.

1. Introduction

Nanotechnology is one of the top technologies that occur at the nanoscale (1×10^{-9}), where nanomaterials behave differently from their bulkier counterparts (Khan et al. 2022). Several methods exist for the fabrication of nanoparticles (NPs), which can be largely divided into physical methods, chemical methods, and biological methods. Recently, researchers have focused on employing a biological method for the synthesis of NPs as they are generally cost-effective, nontoxic, scalable, and eco-friendly (Eid et al. 2023; El Shehawy et al. 2023b). Several types of algae have been extensively explored as potential tools for the green synthesis of NPs at higher rates due to their high capacity for metal accumulation and quite stable NPs in solution (Sharma et al. 2016). In addition, the algae culturing is relatively convenient and easy to handle with several other advantages such as synthesis at low temperatures with greater energy efficiency, less toxicity and safe to the environment (Rajeshkumar et al. 2017). Because of their plentiful growth, ease of use and maintenance, and non-toxicity when utilized to synthesis NPs, marine red algal seaweeds are highly prized (Viswanathan et al. 2023). *Galaxaura rugosa* as red marine algae is a rich source of bioactive compounds (Alzahrani et al. 2020). Our previous study reported the feasibility of using *G.rugosa* alga to synthesize AgNPs (El Shehawy et al. 2023a).

Bimetallic NPs offer greater flexibility with enhanced properties as compared to their monometallic and bulk counterparts (Lee et al. 2006). Recently there has been increasing interest in the design of Ag-Fe bimetallic NPs (Ag-FeBNPs) due to a much larger extinction coefficient of the surface plasmon band. Also, the new structure allows one to add a magnetic functionality to silver properties (Yazdanparast et al. 2020). Therefore, this study aims to investigate the phyco-synthesis of Ag-FeBNPs by the red alga *G. rugosa*. In addition, different characterization processes were used for better identification of the phyco-synthesized nanomaterials of Ag-FeBNPs. It is envisaged that the emerging importance of *G. rugosa* bio-resources for nanobiotechnological applications. To the best of our knowledge, this is the first report on the green synthesis of Ag-FeBNPs using *G. rugosa*.

2. Materials and methods

2.1. Seaweed collection and extract preparation

Marine algae; namely *Galaxaura rugosa* was collected by hand from littoral zone in June 2021 from Zaafarana beach (latitudes 29.06” N and longitudes 32.43” E) located in the Suez Gulf, the Red Sea, Egypt; it is 82 km south of Alain AL Sokhna. With 100 ml of deionized water, approximately 5 g of algal powder was added and left soaking for 24 hours with frequent shaking. The algal extract was filtered through Whatman Filter paper No.1 and the provided supernatant was used to prepare the NPs.

2.2. Phyco-synthesis of Ag-FeBNPs

Phyco-synthesis of Ag-FeBNPs was carried out by mixing solutions of $AgNO_3$ (20 ml, 0.01 M) and $FeCl_3$ (20 ml, 0.01 M) for about 20 min. Then 20 ml of freshly prepared aqueous extract was added to the Ag–Fe solution with constant stirring. The reaction progress was monitored by observing the colour change, indicating the Ag-FeBNPs' formation. The synthesized nanoparticles were centrifuged at 12,000 rpm for 20 min and then washed several times with deionized water for further characterization (Malik et al. 2021).

2.3. Characterization of Ag-FeBNPs

The prepared Ag-FeBNPs were characterized by the UV–vis absorption spectra in the 200–600 nm wavelength range using UV-visible absorption spectroscopy (Uni cam UV-VIS. Spectrometer UV2, U.S.A). XRD analysis was obtained by a DX-1000 X-ray powder diffractometer ran at 40 kV and 30 mA, in the 2θ range of 10°–90°. The size and shape of the nano-colloidal sample were visualized by TEM (JEOLJEM-2100, U.S.A). The crystalline structure was described through the crystallographic experimental technique performed inside the TEM by SAED. Also; the FEI-TITAN 80–300 kV SEM was used to study the morphological structure of the NPs. The elements presented in NPs were determined by EDX integrated into the SEM.

3. Results and discussion

3.1. Description of the used seaweed

Species identification and taxonomical classification were done by a classification expert using fresh samples on the same collection day. Algae are identified as red algae (Rhodophyta) namely; *Galaxaura rugosa* (J.Ellis & Solander), family Galaxauraceae (Fig. 1). The collected alga species were classified according to the previous literature (Aleem 1993).

3.2. UV–Vis Analysis of the phyco-synthesized Ag-FeBNPs

The color variation of the algal extract was obvious on visual observation from yellow to yellowish brown. This transition of color is mainly attributed to the algal active compounds that act as reducing, stabilizing, and capping agents (Malik et al. 2021). UV-visible spectroscopy showed the maximum

absorption peak of Ag-FeBNPs at 327 nm as shown in Fig. 2. This characteristic band can be attributed to the surface plasmon response produced by the interaction between the electrons in the conduction band on the surface of the NPs and the incoming light (Al-Radadi et al. 2022)

3.3. FTIR spectroscopic analysis and XRD analysis of the phyco-synthesized Ag-FeBNPs

The FTIR spectrum of phyco-synthesized Ag–FeBNPs possesses various stretching vibrations, as depicted in Fig. 3a. Major peaks appeared at 3421, 1598, 1384, 1035, and 865 cm^{-1}, in correspondence to the stretching of the N-H bond in amines, and O-H in alcohols, C = C bond stretching in alkene, N-O bond stretching in the nitro compound, O-H bond stretching in carboxylic acid, and C = C bond bending in alkenes, respectively. The Ag-FeBNPs showed a minor shift with slight changes, indicating that the main biomolecules present in extracts were capped to NPs surface as reported by (El-Kassas and El Komi 2014). These results are in good agreement with several previous reports (Carroll et al. 2010; Kamli et al. 2021).

The crystal structure of Ag-FeBNPs is clearly evident in Fig. 3b. The XRD pattern of Ag-FeBNPs from *G. rugosa* give the diffraction peaks at 2θ values of 28.25^0, 29.34^0, 31.57^0, 40.49^0, 46.31^0, and 50.31^0 corresponding to the crystalline planes (210), (220), (1o4), (114), (231), and (042), emphasizing the face-centered cubic phase of the phyco-synthesized NPs. The diffraction peaks observed in the XRD pattern of Ag-FeBNPs are composed of the standard peaks of Ag (JCPDS no. 04-0783) and Fe (JCPDS no. 33–0664), demonstrating the formation of bimetallic phases of Ag and Fe (Malik et al. 2021).

3.4. Morphological Analysis of Ag-FeBNPs

The TEM micrograph of Ag-FeBNPs for *G. rugosa* show an agglomeration of nano-spheres with particle sizes from 19.95 to 37.11 nm, as depicted in Fig. 4a. This coincides well with previous results (Kamli et al. 2021). Figure 4b shows the SAED pattern which exhibits alternating dots and concentric rings, demonstrating that these NPs are polycrystalline (Łukowiec and Radoń 2020).

SEM analyses showed that the particle shapes were spherically shaped, highly distributed, and polydisperse with uniform surfaces (Fig. 4b). This coincides well with previous studies (Kamli et al. 2021). The chemical composition of Ag-FeBNPs was securitized upon EDX analysis, as depicted in Fig. 4d. The Fe and Ag signals shown in the EDX spectrum confirmed that these NPs are composed of AgNPs and FeNPs (Malik et al. 2021). The existence of some extra peaks in the spectrum could be attributed to the participation of algal biomolecules in the NPs' synthesis (Abdel-Raouf et al. 2018).

3.5. Zeta potential analysis

Zeta potential, which refers to the degree of stability of the colloidal particles, was used to determine the degree of electrostatic repulsion between adjacent similarly charged particles. The Ag-FeBNPs show negative potential values of 16.1 mV (Fig. 5). This coincides well with previous studies (Mahmoodi et al.

2019). This negative potential values could be due to the capping impact of the biomolecules present in the algal extracts (Shi et al. 2012).

4. Conclusions

the phyco-synthesis of Ag-FeBNPs offers a promising sustainable and eco-friendly tool for the green synthesis of nanoparticles. The use of *Galaxaura rugosa* has demonstrated good potential applications in the area of nanotechnology as it has been well utilized in the phyco-synthesis of Ag-FeBNPs of remarkable properties as shown using UV-visible spectroscopy, FTIR, XRD, TEM, SAED, SEM, EDAX and zeta potential. Richness of *G. rugosa* extract in different biomolecules that can drive the process of synthesis of nanoparticles shall lead to economically viable means to produce nanoparticles on a larger scale through novel green approaches.

Declarations

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Contributions

All authors contributed to the study conception and design. All authors read and approved the final manuscript.

Data Availability

The data used in the current study are available from the corresponding author on reasonable request.

Ethics declarations

Conflict of interest

We declare that the authors do not have any conflicts of interest.

Ethical approval

Not applicable.

Additional information

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Figures

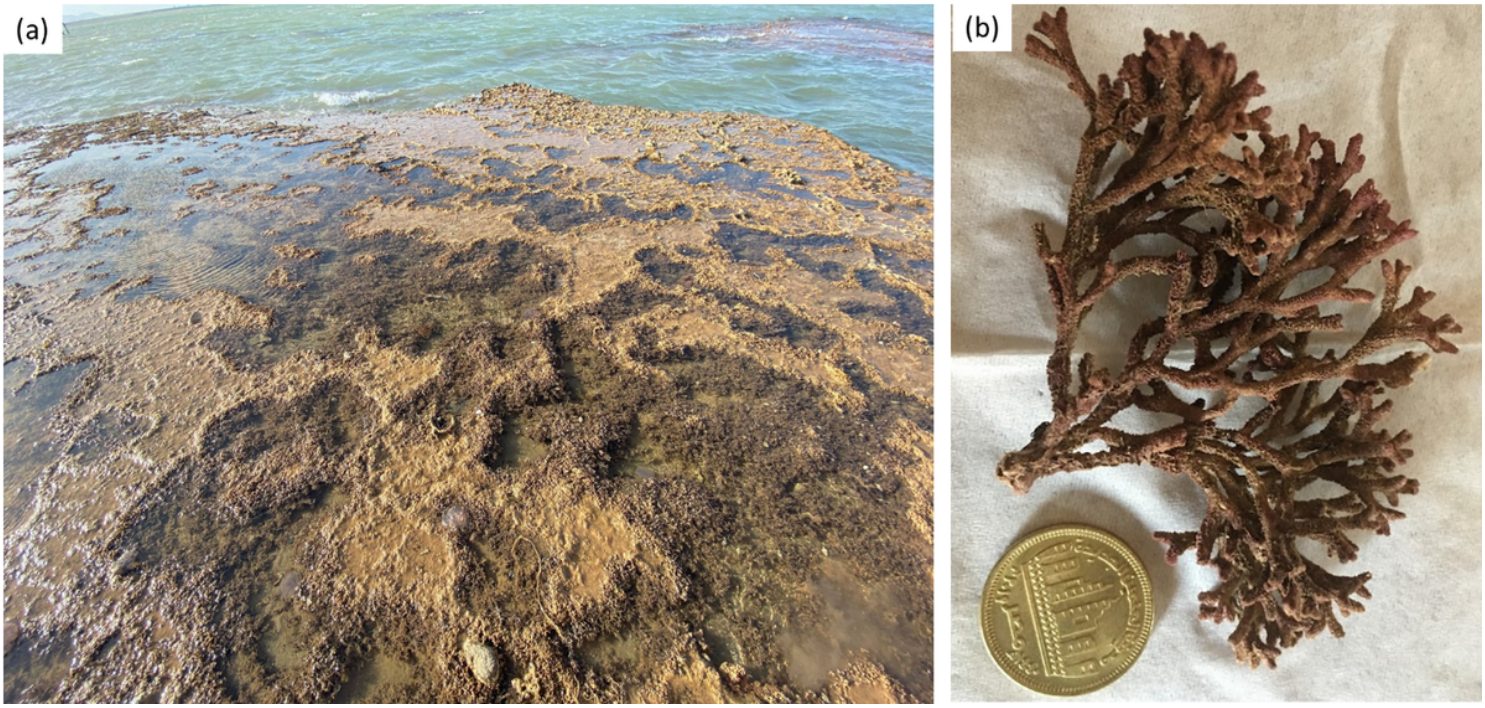


Figure 1

Photos representing **(a)** the study area and the collected seaweed **(b)** *Galaxaura rugosa.*

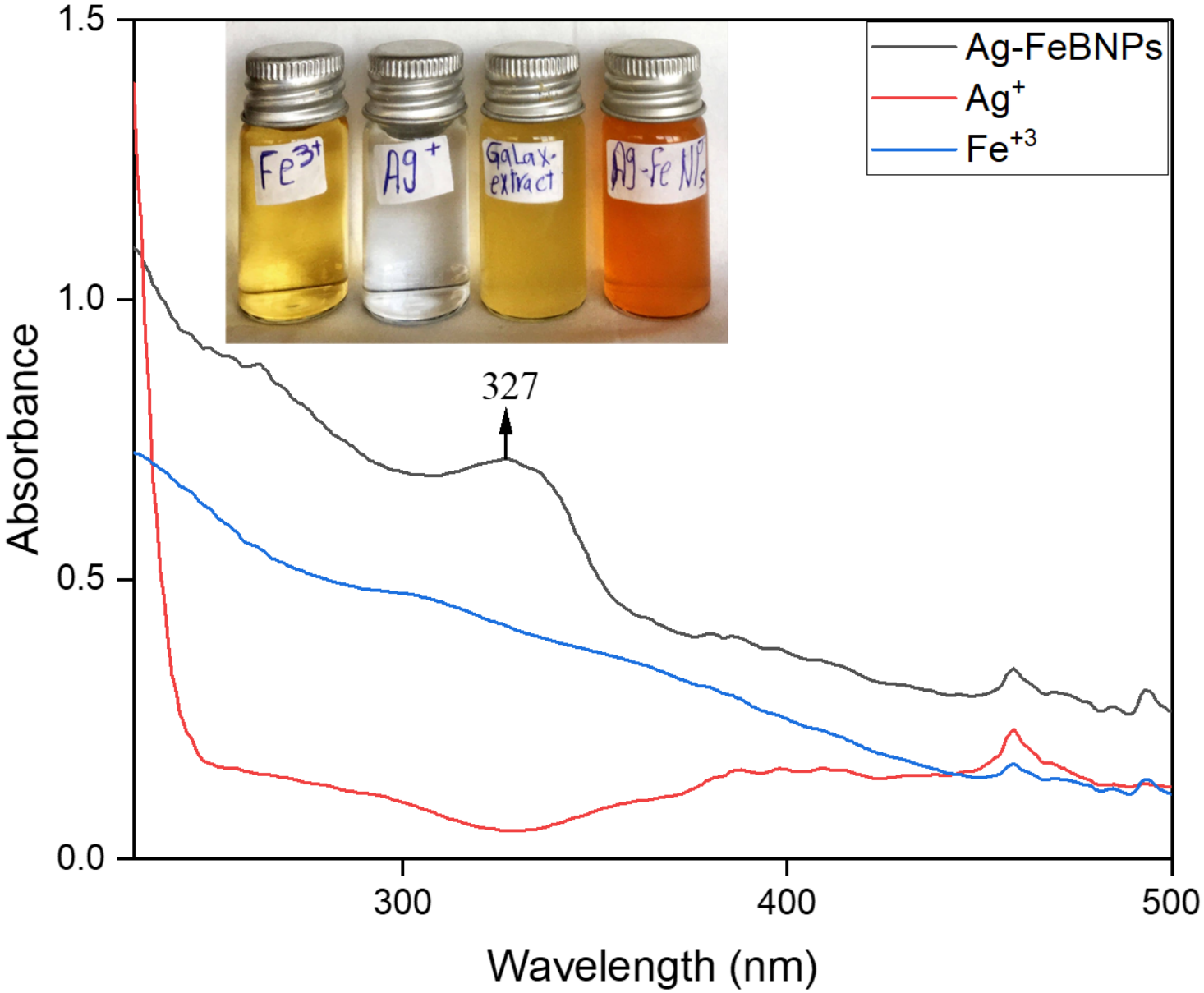


Figure 2

UV–vis spectra of the phyco-synthesized Ag-FeBNPs capped by *Galaxaura rugosa* marine algal extract, inset: shows extract before and after exposure to Ag–Fe solution.

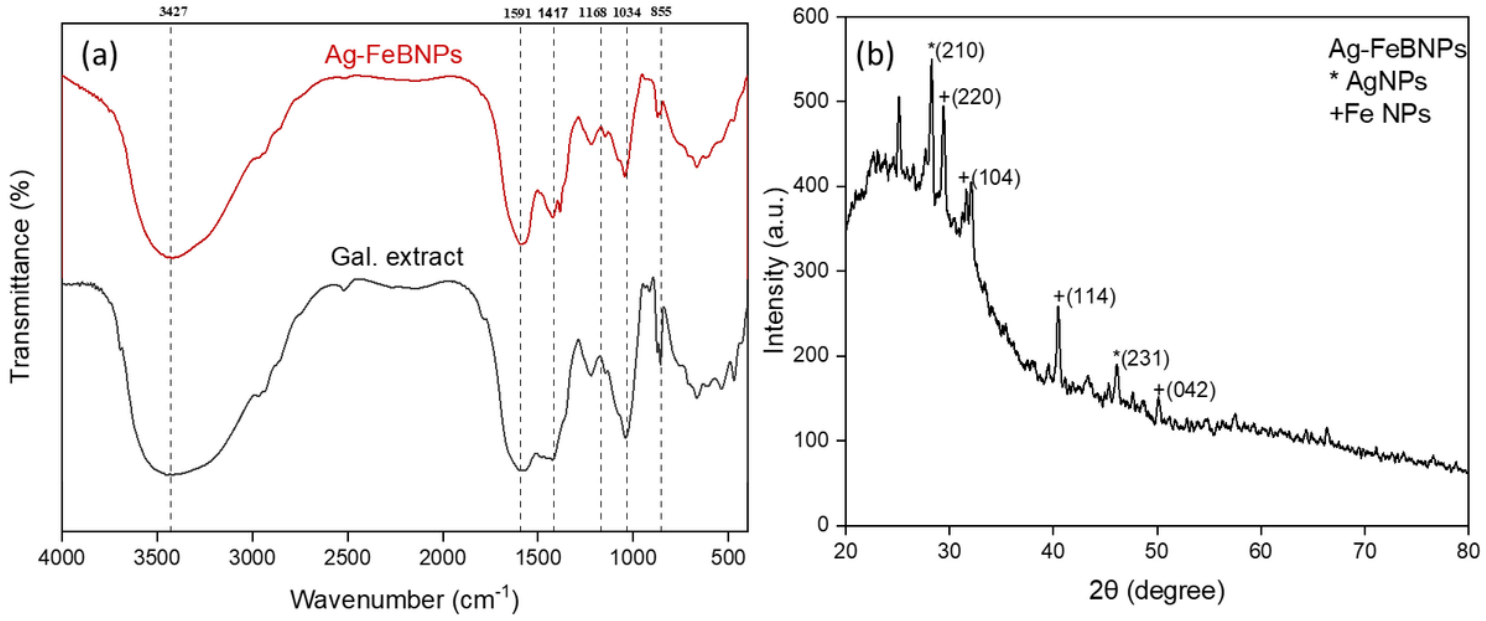


Figure 3

(**a**) FTIR of the phyco-synthesized Ag-FeBNPs and *G. rugosa* marine algal extract; (**b**) XRD pattern of Ag-FeBNPs capped by *G. rugosa* marine algal extract.

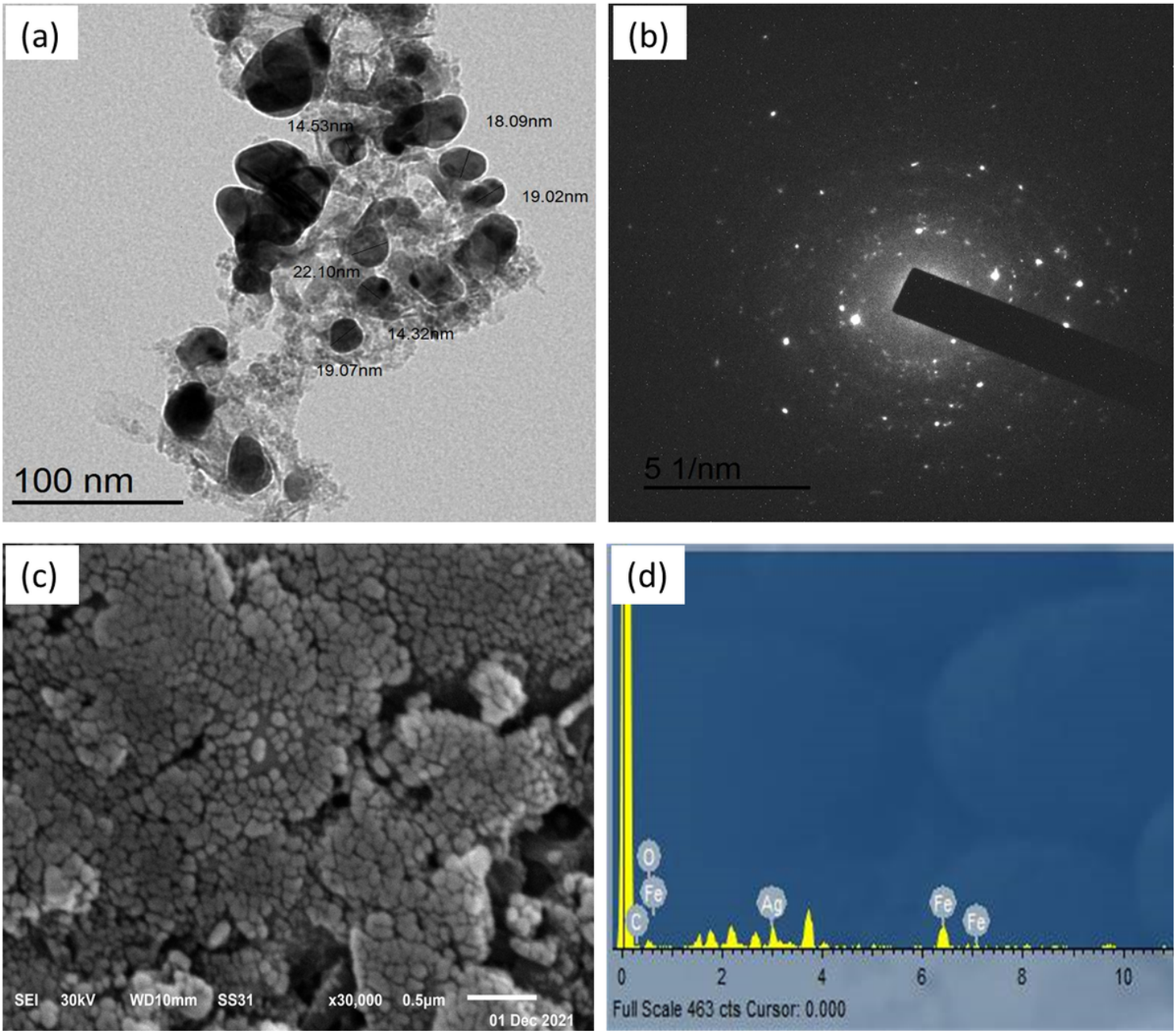


Figure 4

(a) TEM, **(b)** SAED, **(c)** SEM, and **(d)** EDX of the phyco-synthesized Ag-FeBNPs capped by *G. rugosa* marine algal extract.

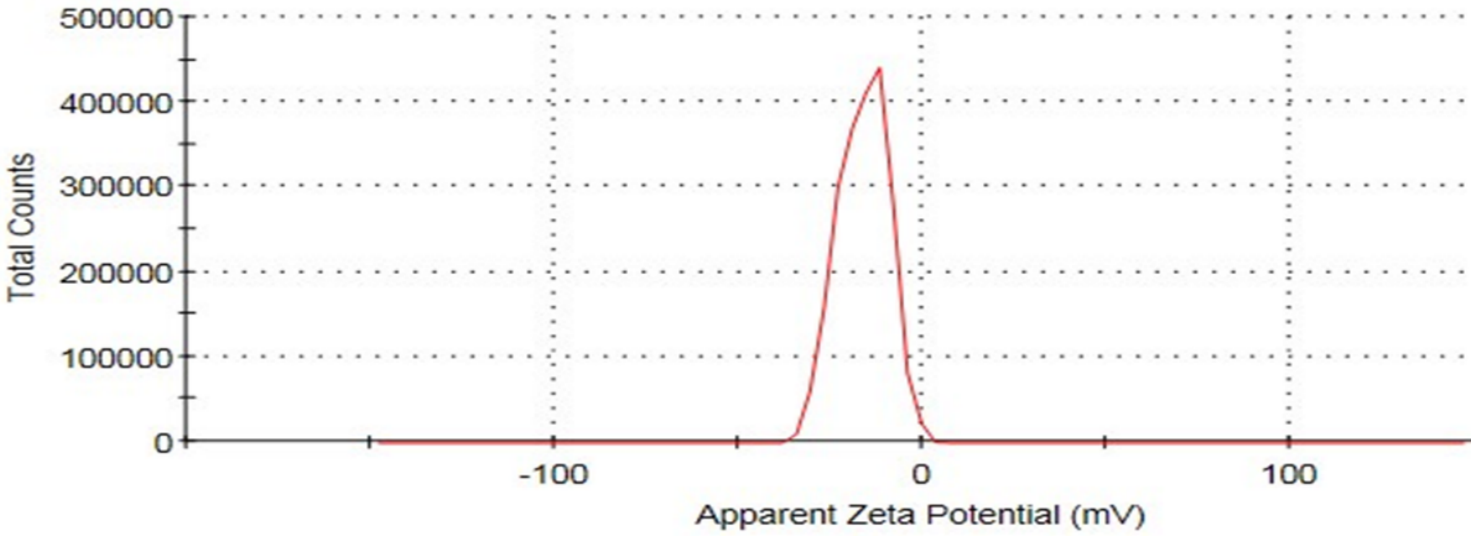


Figure 5

Zeta potential of Ag-FeBNPs phyco-synthesized from *G. rugosa* extract.