

Synthesis of Phytofunctionalized Cr₂O₃ Nanoparticles of Fig Fruit (*Ficus carica* L.) and their Potent Antibacterial Activity

Asma Khalid

asmakhalid2016@gmail.com

University of Education

Ghulam Yaseen

University of Education <https://orcid.org/0000-0002-7456-4365>

Research Article

Keywords: *Ficus carica*, Green synthesis, Chromium oxide nanoparticles, Phytofunctionalization, Antibacterial activity, Multidrug resistance, Sustainable nanotechnology

Posted Date: September 15th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10764212/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations:

Tables 1 is available in the supplementary files section.

Synthesis of Phytofunctionalized Cr₂O₃ Nanoparticles of Fig Fruit (*Ficus carica* L.) and their Potent Antibacterial Activity

Ghulam Yaseen^{*1}, Asma Khalid¹

¹Department of Botany, Division of Science & Technology, University of Education, Lahore, Pakistan
Corresponding Address: Ghulam Yaseen (ghulam.yaseen@ue.edu.pk), Asma Khalid (asmakhalid2016@gmail.com)

Abstract

Antimicrobial resistance poses an escalating global health crisis, underscoring the urgent need for sustainable alternatives to conventional antibiotics. Here, we detail an environmentally friendly method for producing chromium oxide nanoparticles (Cr₂O₃-NPs) using extract from the fruit of the *Ficus carica* fruit as both a reducing agent and a capping agent. The synthesis of crystalline, rhombohedral Cr₂O₃-NPs with an average size of 320 nm and good elemental purity was confirmed through comprehensive analysis using UV-Vis, FTIR, SEM-EDX, and XRD. Phytochemical functionalization imparts significant bioactivity, enabling robust bactericidal performance against WHO-priority gram-positive (*Bacillus subtilis*) and gram-negative (*Escherichia coli*) strains. Remarkably, the inhibition zones at 100 µL (38.4 ± 2.4 mm for *B. subtilis* and 36.5 ± 1.4 mm for *E. coli*) exceeded those of the ciprofloxacin controls. CFU assays further demonstrated near-complete bacterial eradication, highlighting a dose-dependent effect. Mechanistic insights suggest synergistic contributions of reactive oxygen species generation, membrane disruption, and phytochemical capping in enhancing antimicrobial potency. Compared with previously reported plant-derived Cr₂O₃ systems, the present nanoparticles exhibit superior activity and biocompatibility. In addition, the utilization of *F. carica* as a sustainable bioresource highlights the eco-friendly nature of this synthesis route, eliminating toxic chemical reagents and offering a scalable strategy for biomedical nanomaterials. The findings not only validate the antibacterial potential of Cr₂O₃-NPs but also suggest their promising integration into clinical applications such as antimicrobial coatings, wound dressings, and drug delivery systems. This work establishes *F. carica* mediated Cr₂O₃-NPs as a scalable, eco-conscious antimicrobial nanoplatform with strong potential for combating multidrug-resistant infections, aligning with the WHO's vision for next-generation therapeutics.

Keywords: *Ficus carica*; Green synthesis; Chromium oxide nanoparticles; Phytofunctionalization; Antibacterial activity; Multidrug resistance; Sustainable nanotechnology

1. Introduction

Green synthesis, often known as one-pot synthesis, is currently the focus of nanoscience and chemistry Rao et al. (2022). Innovations in dimensions between one and one hundred nanometers, or the "nanoscale," have the potential to shake up many different industries (Barzinjy & Azeez, 2020) (Kumar et al., 2022). The area of

nanobiotechnology has paid considerable attention to the utilization of different biological entities. Nanostructured materials, which have specific properties, are a new research direction in nanotechnology, as they are fabricated from many metals and metal oxides (Park et al., 2011). The synthesis of metallic nanoparticles (NPs) using biological materials including extracts from plant, seed and fruit has gained so much interest due to its environmental friendly nature (Parveen et al., 2016). The properties of biogenically produced NPs are novel and improved and can be applied for various purposes depending on the size, shape and distribution of the NPs (Tang et al., 2007; Thakkar et al., 2010).

The biogenic synthesis approach is really useful for making nanoparticles or NPs because of the way they are physically and chemically. Nanoparticles have high surface area to volume percentage. That make them reactive and important for adsorption, antimicrobial properties, and catalysis etc. This approach can make NPs that are better for living things. So these NPs can be used in ways in the biological field like carrying medicine and helping to make new tissue. This way of making NPs is also better than using chemicals, which can be very bad, for things. It avoids the problems that come with using those chemicals. Nanoparticles are used in areas, including biomedical engineering, cosmetics delivering medicine, managing energy making pharmaceuticals helping chemical reactions and taking care of people's health. These are a few examples of the many uses of nanoparticles (Nigam et al., 2021; Singh et al., 2016).

Numerous attempts have been made to synthesize gold, iron, zinc, copper, nickel, silver, palladium, cobalt, and a host of other metals from plants via extracts. The extracts contained both primary and secondary metabolites, which acted together to generate nanoparticles by reducing the metal ions. Proteins, lipids, and carbohydrates (both simple sugars and polysaccharides) are examples of primary metabolites, while terpenes, flavonoids, tannins, acetogenin, alkaloids, glycosides, etc. are examples of secondary metabolites (Ps & Ks, 2017). Additionally, nanoparticles can be produced chemically and physically, but these methods are expensive and harmful to the environment.

It is reported that the compared to chemical synthesis, nanoparticle production using plant extracts has many benefits, including a high yield, stability, lack of toxicity, low cost, and little impact on the environment (Goel et al., 2023; Gour et al., 2019; Jadoun et al., 2021). Depending on their chemical composition, physical properties, the play role in nutrient uptake, plant defense system (antioxidants etc.), photosynthesis, and plant stress tolerance. Plant extracts serve as cappers and reducers in green chemistry procedures for the biological synthesis of nanoparticles, including copper oxide (CuO), titanium dioxide (TiO₂), zinc oxide (ZnO), calcium (Ca), iron (Fe), tin (Sb), silver (Ag), , and nickel oxide (NiO) (Saritha et al., 2022). Because of their intrinsic cytotoxic properties, NPs are highly efficient against cancer cells and a wide variety of pathogens, including fungus and bacteria (Rakshit et al., 2023).

Among the several nanoparticles derived from metal oxides, the Cr₂O₃ stands out due to its exceptional physicochemical properties, such as its heightened melting point, increased durability, and huge bandgap (~3.4 eV). Among the many uses for Cr₂O₃ nanoparticles are catalysis, photonics, coating materials, and enhanced colorants. The most stable form of chromium oxide is believed to be trivalent Cr₂O₃ nanoparticles (Ahmed Mohamed et al., 2020b). Although Cr₂O₃ nanoparticles exhibit potential, limited research has assessed their biological uses because of the reported harmful effects reported in numerous studies (Alarifi et al., 2016). In order to use Cr₂O₃ nanoparticles in

different biological systems, their biocompatibility is essential. Coating or functionalizing the surfaces of Cr_2O_3 nanoparticles with biogenic compounds can reduce their harmful effects. Phytosynthesizes Cr_2O_3 NPs Utilized in chemistry, anticancer, antileishmanial, antibacterial, electronics (solar energy collectors, microelectronic and fuel cells etc.), and also in medicine field. Coating the surface of Cr_2O_3 with biogenic phytomolecules extracted from plants is one of the most encouraging ways to do this (Rakshit et al., 2023).

Sustainable, resilient, eco-friendly, and scalable nanoparticle production from biological and plant sources is a promising new area of research (Khan, Shahid, et al., 2020b). Notably, nanoparticles produced through plant synthesis demonstrate greater biocompatibility than those created via chemical and physical techniques. Although traditional method have been used for many times, studies have shown that the environmental friendly methods are more effective in synthesis of nanoparticles the reason is that that have less chances of fail in applications, easy to characterize and they are cost effective. This is due to toxic chemicals use in conventional chemophysical and chemical methods for synthesizing nanoparticles. Following multiple washing cycles, the removal of these toxic chemicals from the nanoparticle surface is quite challenging. Consequently, the toxic chemicals presence on the nanoparticles surface reduces their biocompatibility and restricts their potential biological applications. In contrast, the nanoparticles green synthesis via plant based techniques employs phytomolecules as both reducing and capping agents. Additionally, plant-derived phytomolecules have biologically active molecular functions, such as antioxidant, anticancer, and antibacterial capabilities. The biocompatibility and synergistic effect of nanoparticles are enhanced through green production using plants(Khan, Shahid, & Lee, 2020; Khan, Shahid, et al., 2020b).

The fig tree, or *Ficus carica*, is a member of the *Moraceae* family of deciduous trees. The Southwest Asian and Mediterranean regions are the original habitats of this species(Lodhi et al., 1969). Having a pear shape and frequently showing cracks when ripe, the tasty fruits are axillary on leafy branchlets. A white ring encases a mass of seeds in the fruit's interior, which is surrounded by a delicious, jelly-like flesh. Many different sized seeds are present. The bark is smooth and has a silvery gray or ash coloration (Badgujar et al., 2014). These polysaccharides have anti-inflammatory, anti-cancer, antispasmodic, and antioxidant properties (Soni et al., 2014) . Phenolic compounds, anthocyanins, minerals, organic acids, dietary fiber, carbohydrates, vitamins, and several other substances thought to have therapeutic qualities are all abundant in the plant (Mawa et al., 2013; Soni et al., 2014). In a few scientific studies, this plant has demonstrated potential for treating a variety of illnesses and conditions, such as those related to the gastrointestinal system, diabetes, cancer, hypoglycemia, ulcers, lipids, and bacteria (Joshi et al., 2014; Musaeva et al., 2021; Singh et al., 2021).

Multiple organs of *Ficus carica* are responsible for the synthesis of primary and secondary metabolites of plants. Multiple phytochemicals were bring into being in various fig organs, according to Oliveira and colleagues. Fig leaves contained various acids like (fumaric, quinic, malic, citric, oxalic and also shikimic acid), as described by Oliveira *et al.* in 2009. During their high-performance liquid chromatography (HPLC) examination of FC latex. Oliveira *et al.*(Oliveira, Silva, Andrade, Valentao, et al., 2010) find out that many nonessential amino acids ornithine, cysteine, asparagine, serine, glycine, tyrosine, glutamine, and alanine while necessary amino acids like, lysine, phenylalanine, tryptophan, leucine, and histidine were recognized. Fatty acids such as margaric, myristic, pentadecyl,

stearic, palmitic, linoleic, cis-10-heptadecenoic, oleic, elaidic, heneicosylic, lignoceric, arachidic, behenic, and tricosylic were detected in their GC/MS analysis of FC latex. Along with these phytochemicals, they also found various volatile components, such as monoterpenes like β -pinene α -thujene, eucalyptol, linalool, limonene, α -pinene, terpinolene, and epoxylinalool, and sesquiterpenes like α -bourbonene, α -calacorene α -guaiene, trans- α -bergamotene, β -caryophyllene, germacrene D, α -caryophyllene and cadinene. Included in the leaves are glycosidic flavonoids such kaempferol, psoralen, and bergapten as well as coumarins, triterpenoids, and lupeol acetate, and oleanolic acid. The anthocyanin class of phytochemicals, including the glycosides of cyanidin, pelargonidin, and peonidin, were found in fruits (Dueñas, Pérez-Alonso, Santos-Buelga, Escribano-Bailón, et al., 2008).

A new, environmentally friendly, and sustainable approach for green synthesis of Cr_2O_3 nanoparticles by extraction of fruit *Ficus carica* is shown in this paper. *Ficus carica* is a plant known for its numerous phytochemical contents. This research investigated the biogenic capacity of *Ficus carica* for nanoparticle synthesis and provided a comprehensive understanding of the role of plant derived metabolites in nanoparticle production. The utilization of *Ficus carica*, a readily accessible plant, signifies an economical and scalable alternate for traditional chemical and physical methods in the synthesis of Cr_2O_3 nanoparticles, hence offering a promising research opportunity for industrial and also biological applications. This study has revealed the potential of making Cr_2O_3 nanoparticles more biocompatible by using natural substances and decreasing the toxicity of metal oxide nanoparticles.

The focus of this study is the study of physicochemical and biological properties of Cr_2O_3 nanoparticles produced in the environment with the help of extracts from *Ficus carica*. In order to establish a more environmentally friendly synthesis method for nanoparticles, phytochemicals extracted from *F. carica* were used as natural reducing and capping agents after the synthesized nanoparticles were thoroughly characterized using methods such as UV spectroscopy, XRD, SEM, and FTIR. Bioactive substances can improve biocompatibility for potential biomedical applications including tissue engineering and medication delivery. They were evaluated for their antibacterial efficacy against *B. subtilis* and *E. coli*. The research also aims to understand how secondary metabolites including flavonoids, tannins, and terpenoids function as stabilizing and reducing agents during the formation of nanoparticles.

2. Experimental methods

2.1 Bacterial strains and chemicals

All the chemicals and ingredients used for preparation were procured from Merck and Sigma Aldrich. $\text{K}_2\text{Cr}_2\text{O}_7$, with a purity of no less than 99%. Mueller Hinton agar (Oxoid, UK) served as the culture medium for the antibacterial assays, while ethanol ($\geq 99.9\%$ purity, Merck) was employed for sterilization. Ciprofloxacin ($\geq 98\%$ purity, Sigma–Aldrich/Merck) served as the standard antibiotic control. Additionally, the materials used for biological research, along with the bacterial strains *E. coli* (ATCC 1399) and *B. subtilis* (ATCC 465) were obtained from the microbiology department of the University of Punjab, Lahore, Pakistan.

2.2 Plant material

Plant taxonomist Dr. Ghulam Yaseen confirmed the authenticity of the high quality *Ficus carica* fruits bought from a Pakistani herbal medicine store in Lahore. The collected plant samples were accurately identified at the UE Herbarium, and their authenticity was validated by depositing the samples in the Herbarium of the University of Education, Lahore. Voucher samples (No. UOEL-Bot-2024-19) were deposited in the Herbarium for future purposes.

2.3 Preparation of extracts

To eliminate surface contaminants and dust, the fruit of the *Ficus carica* fruit was thoroughly washed using tap water and deionized water. The samples were subsequently desiccated in the shade at a temperature of approximately 25°C. The plant material was crushed into smaller fragments and subsequently powdered into a fine powder via a mechanical grinder after it had dried. One hundred milliliters of double distilled water was combined with 25 g of each pulverized sample for extraction. The aqueous extract was obtained by heating the mixture and continuously stirring it at 100°C for 6 hours (Onyebuchi & Kavaz, 2020). The solution was filtered two or three times with Whatman filter paper once it cooled to ambient temperature (Niroumand et al., 2015), and the extract was kept at 4°C for further production of Cr₂O₃ nanoparticles (Moloudizargari et al., 2013).

2.4 Biosynthesis of chromium oxide (Cr₂O₃) nanoparticles

Ficus carica fruit extract (pH: 7.5) is typically used to reduce K₂Cr₂O salt to create Cr₂O₃NPs. For this purpose, 50 ml of filtered fruit extract from *Ficus carica* was combined with 3 g of K₂Cr₂O salt, and the mixture was heated to 60°C while being constantly stirred at 500 rpm for 2 hours. The resulting mixture was centrifuged for 25 minutes at 10,000 rpm. To eliminate any unwanted biological items from the sediments, the pellet containing the Cr₂O₃NPs was meticulously cleaned three or four times with distilled water before being centrifuged. After three hours at approximately 100°C, the pellets at the bottom of the Falcon plate which were identified as Cr₂O₃NPs were dried into a powder. Additionally, crystalline Cr₂O₃NPs were obtained by calcining this powder in a furnace. Furthermore, many characterizations have been carried out. The study design of Cr₂O₃NPs, from synthesis to characterization and biological applications (Iqbal, Abbasi, Munir, Uddin, Kanwal, Mahmood, et al., 2020).

2.5 Characterization of chromium oxide (Cr₂O₃) nanoparticles

Various analytical techniques have been employed to characterize synthesized Cr₂O₃ nanoparticles. The optical absorbance was assessed via a Shimadzu UV-2600 spectrophotometer. Fourier transform infrared spectroscopy (FTIR), which uses a PerkinElmer Spectrum Two ATR system, was employed to recognize the functional groups of phytochemicals which plays vital role in nanoparticle reduction and stabilization. The morphology, particle size, and the composition of elements and morphology of nanoparticles were analyzed using (SEM) scanning electron microscopy and energy-dispersive X-ray spectroscopy (EDX) with ZEISS EVO 18 equipment. The crystalline structure and phase composition were analyzed through X-ray diffraction (XRD) via a PANalytical X'Pert PRO diffractometer (Saod et al., 2024).

2.6 Minimum inhibitory concentration (MIC)

To determine the MIC of the Cr₂O₃ nanoparticles, the agar dilution method was employed. Using concentrations ranging from 1000 µg/mL to 7.81 µg/mL, we prepared Mueller–Hinton agar plates by including Cr₂O₃ nanoparticles in multiple twofold dilutions. We aimed to cover a broad spectrum of circumstances by selecting this concentration range. Bacterial growth was halted at the maximum concentration (1000 µg/mL), and the lowest concentration (7.81 µg/mL) allowed us to determine the minimum level at which bacteria could not grow. Bacteria from each test strain were uniformly distributed (10⁶ CFU/mL) across the agar plates. Plates were incubated at 37 °C for 1 day, after that proteins were allowed to unfold. The MIC emerged as the smallest nanoparticle dose that completely stopped any visible bacterial growth (Parvekar et al., 2020).

2.7 *Determination of Colony Forming Units (CFUs)*

The bacterial suspension was removed aseptically from samples below the turbidity level and spread on a Mueller – Hinton agar spread plate according to the standard method and the colony-forming units (CFUs) were counted. The plates were left for 24-hour incubation at 37 °C to enable colonies to grow. After incubation, the number of colonies was counted manually and the number of bacteria given in CFU/mL taking into consideration the dilution factor. This enumeration not only demonstrated the viability of the bacteria but also assisted in separating out bacteriostatic from bactericidal effect of test samples. Diameter of the zone of inhibition around each well was measured using digital Vernier caliper and the antibacterial activity was determined. Data are given as the means ± standard deviations (SDs) of three independent experiments.

2.8 *Antibacterial activity of aqueous extracts and Cr₂O₃ nanoparticles*

The bacterial stains were preserved on slants of Mueller-Hinton agar at 4°C for analysis. Both the fruit extract of *Ficus carica* and the Cr₂O₃ nanoparticles had antibacterial activity against the tested bacteria. The evaluation of the resistance was done by the standard agar well diffusion method. To ensure that the bacterial cultures were active, they were transferred to the Mueller–Hinton broth and incubated at 37 °C for 24 hours prior to testing. The bacterial lawns were achieved aseptically applying the bacterial inoculum on sterile Muller–Hinton agar. The test samples (20, 40, 60, 80 and 100 µL) were introduced into the agar-filled wells that were 8 mm in diameter. Negative control was sterile distilled water, positive control was ciprofloxacin (10 µg/mL, 100 µL). The clear zones were precisely determined after 1 day at temperature of 37°C and after incubation, to measure the degree of antibacterial activity (Masadeh et al., 2015).

2.9 *Statistical analysis*

All measurements were repeated 5 times. One-way ANOVA in SPSS 20 program was used to analyze the data. For significant difference ($p < 0.05$) among the treatments Tukey's test was used.

3. *Results and Discussion*

3.1 *Synthesis of Cr₂O₃ NPs and their probable mechanism of formation*

The Cr_2O_3 nanoparticles were synthesized by reducing potassium dichromate ($\text{K}_2\text{Cr}_2\text{O}_7$) with *Ficus carica* fruit extract at neutral pH (7.5). In this process, 50 mL of filtered *F. carica* extract was mixed with 3 g of $\text{K}_2\text{Cr}_2\text{O}_7$ salt, heated to 60 °C, and stirred continuously at 500 rpm for 2 hours. The mixture was centrifuged for 25 minutes at 10,000 rpm, and the resulting pellet was washed many times with the help of distilled water to remove impurities. The obtained Cr_2O_3 nanoparticles were dried at 100 °C for 3 hours and subsequently calcined in a furnace to improve crystallinity (Ramesh et al., 2012). The rich phytochemical composition of *F. carica* includes organic acids, amino acids, flavonoids, coumarins and triterpenoids, leading to the successful synthesis of Cr_2O_3 nanoparticles. These metabolites are reducing and stabilizing agents used for nucleation of the nanoparticles as well as to cap the surface of the nanoparticles to increase their stability and biological activity (Dueñas, Pérez-Alonso, Santos-Buelga, & Escribano-Bailón, 2008; Oliveira, Silva, Andrade, Valentão, et al., 2010; Oliveira et al., 2009). These phytoconstituents help to enhance the antimicrobial property of the developed particles and facilitate the efficient bioreduction of chromium ions.

Previous studies have effectively generated Cr_2O_3 nanoparticles from medicinal plants such as *Abutilon indicum* (L.) and other plants. Not all plant-derived nanoparticles are suitable for biomedical applications because some plants may lack bioactivity or introduce hazardous effects, even if some plants can be used to generate bioactivity materials including gold, silver, ZnO nanoparticles, and 1D-MoO₃ nanorods (Khan, Shahid, et al., 2020a). *Ficus carica*'s high concentration of non-toxic bioactive chemicals makes it a superior choice for green synthesis.

The materials obtained by the reduction of FeCl_3 with *F. carica* extract, Cr_2O_3 nanoparticles, exhibited an important antibacterial activity, being capable of inhibiting both gram-positive (*Bacillus subtilis*) and gram-negative (*Escherichia coli*) germs. Furthermore, the nanoparticles with the phytochemicals showed antioxidant and anticancer properties, highlighting their potential for multifunctional therapeutic applications (Prashanth et al., 2018). Compared to chemically generated Cr_2O_3 nanoparticles, the green created particles were more biocompatible, supporting the idea that plant metabolites can lessen the harmful effects of metal oxide nanoparticles. Overall, the findings indicate that *F. carica* plays a crucial role in the ongoing synthesis of Cr_2O_3 nanoparticles as a reducing agent and a source of physiologically active stabilizers (Figure 1). This method not only highlights the usage of produced nanoparticles as exceptional bio medical and environmental applications, but it also validates the significance of *F. carica* as a biogenic source.

Figure 1: Mechanism of pathways of synthesis of Cr_2O_3 nanoparticles from *Ficus carica* Fruit extract

3.2 Characterization of the plant extract and Cr_2O_3 nanoparticles

Different analysis techniques have been used to characterize the synthesized copper oxide Cr_2O_3 nanoparticles in terms of their properties (chemical and physical). The UV-visible (UV-Vis) spectroscopy results

showed that the nanoparticles gave rise to a specific absorbance peak. This is in agreement with the phenomenon of surface plasmon resonance observed. Fourier transform infrared spectroscopy (FTIR) was used to examine the molecular structure of the plant, and functional groups were identified within. The energy-dispersive X-ray (EDX) spectroscopy showed that the main elements analyzed were copper and oxygen. Scanning electron microscopy (SEM) was used to get insight into the surface morphology of the nanoparticles. X-ray diffraction (XRD) was used to identify what crystals are found inside the nanoparticles and to calculate the typical size of the nanoparticle.

3.2.1 UV-visible spectroscopy analysis of *Ficus carica* fruit extract and Cr_2O_3 NPs

The UV-VIS absorption spectrum (200-800nm) of the fruit extract of *Ficus carica* showed strong absorption at 248nm as seen in figure 2 and 3. The strong absorption in UV region indicate presence of bioactive secondary metabolites, likely phenolic acids which are known to have high molar absorptivity at this wavelength. The antioxidant activity of the extract is also increased by phenolics which are also crucial in the reduction and stabilization of nanoparticles (Patle et al., 2020). The absence of peaks above 300 nm indicates that the primary components of the fruit extract could be simple aromatic systems or phenolics that are relatively less conjugated.

Fruit derived polyphenols rarely have prolonged conjugated structures unless hydrolyzed or polymerized. The extract's reducing and stabilizing capabilities in green synthesis are supported by the single strong peak at 248 nm, which confirms the presence of phenolic chemicals (Anandhi et al., 2017). The creation of chromium oxide nanoparticles (Cr_2O_3 -NPs) via *Ficus carica* fruit extract was validated by a color change in the reaction mixture, indicating efficient bioreduction of chromium ions. The production of nanoparticles was confirmed by UV-Vis spectrophotometry and their optical properties studied. In UV-Vis spectrum (Figure 2), three absorption peaks were observed at 248, 294 and 391 nm (Behzadi et al., 2015). The fruit extract has significant absorptive characteristics in the UV region, with a sharp absorption seen at 248 nm, suggesting that this extract contains phenolic chemicals, specifically phenolic acids, which have a tendency to absorb strongly in the UV region. The second peak at 294 nm might result from the presence of carbonyl groups in flavonoids that bind metal ions during the preparation of nanoparticles. The presence of the absorption band at 391 nm suggests the production of Cr_2O_3 nanoparticles as most importantly (Saranya & Sekar, 2016).

The semiconductor nanoparticles can have plasmon like resonance properties and have a long conjugation peak in the visible band. The shift to a wider shape of the spectrum with a large number of peaks indicates the complicated interactions between phytochemicals formed from the plants and the chromium ions, including both stabilization and reduction. Absorption of bioactive capping agents in *Ficus carica* fruit extract is essential to stabilize, shape and preserve biological activity of nanoparticles, which shows the effective production of Cr_xO_y -NPs. The spectrum indicated that *Ficus carica* extract can be a reliable biogenic source for the synthesis of metal oxide nanoparticles which is confirmed by previous studies of green synthesized Cr_2O_3 nanoparticles (Ajitha et al., 2015; Kasprzak et al., 2015).

Figure2: UV-visible spectrograms of *Ficus carica* Fruit extract

Figure 3: UV-visible spectrograms of Cr₂O₃ NPs through *Ficus carica* Fruit extract

3.2.3 Fourier Transform Infrared Spectroscopy (FT-IR)

For the identification of the functional groups that involved in reduction and stabilization of the metal ions, Fourier transform infrared (FTIR) spectrum of the *Ficus carica* fruit extract was recorded in between 4000–500 cm⁻¹ (4 and 5). Multiple absorption bands were observed in the spectrum, which suggested the presence of several phytoconstituents. The band at 3598.56 cm⁻¹ belongs to the O–H stretching vibrations of hydroxyl group that are present in alcohols and phenolic compounds indicating the presence of polyphenols and flavonoids. This is confirmed by the appearance of other O–H bands at 3404.60 cm⁻¹ and 3206.34 cm⁻¹. In the bio reduction of metal ions, functional groups act as electron donors. The high peak at 2566.13 cm⁻¹ could be attributed to the presence of O–H overtone vibrations or weak C–H stretching, which are characteristic of organic acids and sugars [20]. The bands at 2278.87 cm⁻¹ and 1640.00 cm⁻¹ are the vibrations of C≡N or C≡C stretching and C=C stretching of the aromatic rings, respectively. The presence of alkynes, nitriles and aromatic compounds suggests the presence of phytochemicals that are commonly found in fruit extracts. The carbonyl C=O stretching vibration at 1664.71 cm⁻¹ is indicative of aldehydes, ketones or esters, which are possible constituents of organic acids or flavonoids (Khan, Shahid, et al., 2020a) . The distinct and intense absorption band at 633.24 cm⁻¹ in the fingerprint region suggests the presence of metal oxygen bonds. This is not proof for the formation of nanoparticles, but it suggests that there might be some interaction between the metal ions or the extract might contain chelation sites. Based on the FTIR spectrum, a fruit extract of *Ficus carica* contains several bioactive compounds such as polyphenols, flavonoids, organic acids and aromatic constituents, which could be used as good reducing and stabilizing agents for the synthesis of metal oxide nanoparticles (Iqbal, Abbasi, Munir, Uddin, Kanwal, & Mahmood, 2020).

The FTIR spectrum of the synthesized Cr₂O₃ nanoparticles was obtained from 4000 to 500 cm⁻¹, which shows several different absorption bands, indicating the involvement of various functional groups of phytochemicals during the reduction and stabilization process. The peak of 3349.97 cm⁻¹ is rather large, and is assigned to the OH stretching mode of hydroxyl groups, typically present in phenolic compounds and alcohols. This suggests that the plant extract contains polyphenols and flavonoids, which seem to be the main reducing agents in the synthesis of the Cr₂O₃ nanoparticles. The peak at 2713.46 cm⁻¹ is indicative of C–H stretching, which is commonly linked to aldehydes or carboxylic acids or potentially an overtone of the hydroxyl group. This implies that there are organic acids and sugars present which could contribute to the stabilization of the nanoparticles (Ahmed Mohamed et al., 2020a) . C=C or C≡N stretching vibrations are assigned to the peaks at 2360.51 cm⁻¹ and 2154.88 cm⁻¹, respectively, suggesting the presence of alkynes or nitriles, the common structures of plant-based phytochemicals. A number of bands between 1986.28 and 1339.74 cm⁻¹ are assigned to various bending and stretching vibrations of C=O, C=C, N–H, other aromatic groups, indicating the presence of flavonoids, amides, and other aromatic compounds which are involved in chelation and stabilization. The bands around 1059.84 cm⁻¹ are characteristic of C–O stretching, which is typical of alcohols, esters, or ether groups, and supports the presence of bioorganic stabilizing agents. The presence of a sharp peak at 644.91

cm^{-1} in the fingerprint region is related to the stretching vibrations of Cr–O bonds, which is indicative of the formation of chromium oxide (Cr_2O_3) nanoparticles (Hassan et al., 2019). It is noted that metal–oxygen bonds are a typical feature of metal oxide nanoparticles, which validates the synthesis of these particles. The FTIR spectrum revealed that the bioactive compounds like flavonoids, organic acids, polyphenols and also nitrogen containing compounds played a significant role in the reduction of chromium ions and stabilization of the formed Cr_2O_3 nanoparticles in the green synthesis process.

Figure 4: FT-IR spectrograms of *Ficus carica* fruit extract

Figure 5: FT-IR spectrograms of Cr_2O_3 synthesis from *Ficus carica* fruit extract

3.2.4 Scanning electron microscopy (SEM) analysis

The synthesized chromium oxide (Cr_2O_3) nanoparticles were examined using scanning electron microscopy (SEM) to investigate their surface morphology, which is visible in Figure 6. SEM images with magnifications of 20 μm and 30 μm revealed particles with heterogeneous, aggregated and irregular shapes. The clusters are made from loosely packed granules and flakes, meaning that the plant extract likely played a major role in reducing the chromium ions as well as stabilizing the obtained nanoparticles. The particle surfaces are rough and irregular, implying that the polycrystalline property is often desirable for catalytic and biological applications. The average particle size of the Cr_2O_3 nanoparticles were estimated to be in the range of 300 to 350 nm. The plant-mediated synthesis may have capped the particle size and controlled their growth which resulted in a relatively uniform distribution of the particles in the field. They observed the morphology and found that bioactive phytochemicals play a role in the synthesis, which increases surface area and reactivity, crucial for antimicrobial activity and photocatalysis applications (Isacfranklin et al., 2020)

Figure 6. SEM micrograph of Cr_2O_3 nanoparticles synthesized using *Ficus carica* fruit extract at 20 μm scale and 30 μm scale

3.2.5 Energy dispersive X-ray (EDX) analysis

Energy-dispersive X-ray (EDX) spectroscopy used to examine the elemental composition of the synthesized nanoparticles of Cr_2O_3 as shown in Figure 7. The emission peaks noted in the EDX spectrum were two in number with one emission at ~ 2.3 keV representing oxygen (O) and a second emission at ~ 5.4 keV representing chromium (Cr). The peaks were unique and confirmed the successful preparation of chromium oxide nanoparticles, which is consistent with the previous work on green synthesized Cr_2O_3 system (Iqbal, Abbasi, Munir, Uddin, Kanwal, & Mahmood, 2020). The predominant element in the composition was found to be chromium, at 73.45% of the total weight of the sample and 42.30% of the total atomic percentage, while oxygen made up the remaining 26.55% of the weight and 57.70% of the total atomic percentage. The near-stoichiometric Cr:O ratio is in good agreement with the theoretically

calculated value for Cr_2O_3 (2:3), indicating the structural integrity and stability of the nanoparticles obtained. The lack of extra peaks associated linked to supplies further emphasizes that there is no contamination of foreign plant metabolites or plant salt precursor. The elemental mapping of the specific areas further confirmed the uniform distribution of chromium and oxygen in the nanoparticles, thus reinforcing the homogeneous synthesis. The uniformity of atomic percentages throughout different replicates suggests very good reproducibility of the biosynthetic process. The high content of chromium and the correct balance of oxygen showed that the functional groups of the extract from *Ficus carica* are very efficient at reducing and capping without being contaminated with chemicals. The elemental integrity and purity of the system derived from The *F. carica* are better than those of chemically manufactured Cr_2O_3 nanoparticles, which often contain non-stoichiometric compositions or residual contaminant peaks due to incomplete reduction or the presence of contaminants from stabilizers (Khan et al., 2021) . The high compositional correctness not only proved the effectiveness of green synthesis, but also holds a biological relevance as contaminant-free nanoparticles are more likely to exhibit better biocompatibility and low cytotoxicity (Cheah et al., 2025) . The EDX results confirm the phase purity, stoichiometric stability and absence of unwanted impurities in the biosynthesized nanoparticles of Cr_2O_3 . This compositional precision gives them a solid base for their improved anti-microbial effect, since purity of the particles and surface chemistry plays an important role in their ability to interact with cell membranes of microbes.

Figure 7: EDX of Cr_2O_3 nanoparticles of *Ficus Carica* fruit

3.2.6 X-ray diffraction (XRD) analysis

The X-ray diffraction (XRD) analysis used to confirm the crystalline structure of the Cr_2O_3 nanoparticles synthesized as shown in Figure 8. The diffraction pattern exhibited distinct and clearly defined peaks at 2θ values of 35.116° , 40.590° , 44.722° , 49.622° , 53.962° , 58.248° , 66.162° , 74.278° , and 77.049° , corresponding to the (104), (006), (113), (202), (-204), (211), (214), (208), and (119) crystallographic planes, respectively (Bokuniaeva & Vorokh, 2019; Mohan & Renjanadevi, 2016). The observed diffraction peaks align well with the conventional reference pattern for rhombohedral Cr_2O_3 (JCPDS Card No. 96-901-5693), confirming the successful synthesis of chromium oxide nanoparticles. The optimized lattice parameters were found to be $a = 4.7140 \text{ \AA}$, $b = 4.7140 \text{ \AA}$ and $c = 13.0290 \text{ \AA}$, which correspond to a corundum-type structure. The absence of secondary peaks from impurity species, such as $\text{Cr}(\text{OH})_3$, or other oxide phases, suggests that the product has high purity and is also synthesized efficiently. The sharp reflections at $2\theta = 35.116^\circ$ and 44.722° are from the (104) and (113) crystallographic planes, respectively, revealing the high crystallinity of the synthesized Cr_2O_3 nanoparticles.

Crystallite size of nanoparticle was calculated from the Scherrer equation, is estimated to be $\sim 320 \text{ nm}$, which suggests that relatively large and well-ordered crystallites have formed. The crystallite size range of $40\text{--}120 \text{ nm}$ is also reported for similar studies on Cr_2O_3 nanoparticles prepared using *Ficus carica* extract, indicating the phytochemical composition of the *Ficus carica* extract could have played a role in controlling the growth and stability

of the nanoparticles (Iqbal, Abbasi, Munir, Uddin, Kanwal, & Mahmood, 2020). The larger crystallite size observed in this study could enhance the mechanical stability of the nanoparticles, and their phytochemical stabilization will ensure surface activity for biological interaction. Compared to chemically produced Cr₂O₃ nanoparticles, which often show larger and less intense peaks that are due to defects or incomplete crystallization (Ahmed Mohamed et al., 2020a). The acute and vivid reflections here validate the enhanced structural organization attained via green synthesis. This is beneficial and directly relates to an improvement in the antibacterial activity, photocatalytic activity, and stability of the nanoparticles in biomedical applications, which is directly related to the increased crystallinity (Khan et al., 2021). The results showed that the synthesis of the nanoparticles of Cr₂O₃ using *F. carica* leads to the generation of phase-pure highly crystalline nanoparticles that have excellent structural stability and can be considered as promising candidates in biomedical and environmental applications.

The results are consistent with previous studies on green synthesized Cr₂O₃ and validate the effectiveness of using green synthesis to produce highly crystalline and phase-pure Cr₂O₃ nanostructures. The crystallite size of the synthesized nano particles of Cr₂O₃ was determined by using scherrer equation. The acquired parameters from X-ray diffraction (XRD) are listed in Table 1 such as 2θ values, (hkl) planes, full width at half maximum (FWHM), d-spacing, lattice strain and crystallite size. The average crystallite size of the Cr₂O₃ nanoparticles obtained by using the *Ficus carica* extract was found to be 320 nm. The crystallite size (D) was obtained by using the Scherrer equation:

$$D = K\lambda/\beta hkl \cos\theta$$

In this equation:

- D is the standard crystallite size,
- K is the form factor (usually 0.9),
- λ is the X-ray wavelength (1.5406 Å⁰ for Cu Kα radiation),
- β is the full width of the diffraction peak at half maximum (FWHM) in radians,
- θ is the Bragg angle of the diffraction peak.

This analysis confirmed the formation of relatively large and well-ordered Cr₂O₃ crystallites, further supporting the high crystallinity of the synthesized material.

Table 1: XRD parameters of Cr₂O₃ nanoparticles prepared using *Ficus carica* fruit extract

[Figure 8: XRD representation of Cr₂O₃ nanoparticles through Fruit extract of *Ficus carica*]

3.3 Antibacterial activity of extracts and their Cr₂O₃ nanoparticles

The antibacterial efficacy of aqueous fruit extracts of *Ficus carica* (FE) and its green-synthesized Cr_2O_3 nanoparticles was evaluated against gram-positive (*Bacillus subtilis*) and gram-negative (*Escherichia coli*) bacterial strains. The assessment was performed via the agar well diffusion technique and colony-forming unit (CFU) tests. A positive control (PC; ciprofloxacin) and a negative control (NC; sterile distilled water) were included to validate the antibacterial efficacy of the test samples. Figure 9 and 10 shows a dose-dependent increase in the antibacterial activity of both bacterial strains. The greatest inhibition of *B. subtilis* was recorded with FNP-100 μL (38.4 ± 2.4 mm), which was greater than that of the positive control ciprofloxacin (100 μL) (PC: 36.2 ± 1.8 mm). Likewise, 100 μL of FE (29.6 ± 2.6 mm) had significant inhibitory effects but was inferior to the effects of the nanoparticles. The minimal bactericidal effect was observed for FE-20 μL (4.1 ± 1.1 mm). A similar pattern was noted in the case of *E. coli*. The FNP-100 μL mixture demonstrated the greatest inhibition (36.5 ± 1.4 mm), equal to that of the positive control ciprofloxacin (100 μL) PC (36.3 ± 0.5 mm), whereas the FE-100 μL mixture (29.4 ± 0.6 mm) had a modest effect. Minimal inhibition was observed with FNP-20 μL (3.9 ± 0.3 mm) and FE-20 μL (4.2 ± 0.4 mm). The negative control demonstrated no zone of inhibition throughout all testing conditions, indicating that the observed antibacterial activity was exclusively due to the plant extracts and manufactured nanoparticles.

To validate antibacterial effectiveness, CFU counts were conducted following incubation. In the case of *B. subtilis*, treatment with 100 μL of FNPs yielded the lowest colony count (35.33 ± 2.52), followed by FE at 100 μL (43.67 ± 4.73). The values are analogous to those of PC (44.33 ± 5.86) and markedly lower than those of NC (484.00 ± 3.61), indicating robust bactericidal activity at elevated dosages. Similarly, 100 μL of FNPs diminished the number of *E. coli* colonies to 40.33 ± 6.66 , whereas 100 μL of FE resulted in 44.33 ± 4.04 , both of which were similar to the efficacy of the positive control (46.33 ± 4.04). The NCs resulted in 458.67 ± 8.50 colonies, indicating a substantial bacterial load in the absence of any antimicrobial treatment. Both experiments unequivocally exhibited concentration-dependent bactericidal efficacy for FE and FNPs, with nanoparticles typically surpassing crude extracts. The greater efficacy of FNPs is probably attributable to their reduced particle size and improved contact with bacterial cell membranes, resulting in more effective growth suppression as shown in figure 11 and 12.

Comparison of the bactericidal efficacy of *Ficus carica* fruit extract and Cr_2O_3 nanoparticles with previous findings on eco-friendly Cr_2O_3 nanostructures derived from alternative plant extracts. The antibacterial activity of green-synthesized Cr_2O_3 nanoparticles (FNPs) from *Ficus carica* was compared with that of analogous Cr_2O_3 nanoparticles documented in prior investigations. In our work 100 μL of FNPs caused a zone of inhibition of 38.4 ± 2.4 mm against *Bacillus subtilis* and 36.5 ± 1.4 mm against *Escherichia coli* showing antibacterial activity. The zones of inhibition are much larger than those reported for Cr_2O_3 nanoparticles made using Citrus limon extract, which had a zone of 22 mm against *Streptococcus mutans* (Mohan & Renjanadevi, 2016). In the way Cr_2O_3 nanoparticles made with honey as a reducing agent had a 10 mm zone against *E. Coli*, which is much smaller than the activity seen in this study. Also studies using *Rhamnus virgata* and *Abutilon indicum* (L.) as green sources have tested the effect of Cr_2O_3 nanoparticles against different bacteria, including *Staphylococcus aureus*, *Bacillus subtilis* and *Salmonella typhi* but specific zones of inhibition have not been given (Iqbal, Abbasi, Munir, Uddin, Kanwal, & Mahmood, 2020; Sangwan & Kumar, 2017). Still these findings support the effectiveness of green synthesized Cr_2O_3 nanoparticles. This study not shows this ability but also gives statistical proof of the better antibacterial effect of FNPs against both types of

bacteria. These results suggest that using *Ficus carica* to make Cr_2O_3 nanoparticles may offer antibacterial effect, than other plant-based methods.

Figure 9: Effects of Cr_2O_3 nanoparticles indicating ZOI in *Escherichia coli* culture

Figure 10: Effects of Cr_2O_3 nanoparticles indicating ZOI in *Bacillus subtilis* culture

Figure 11: Effects of Cr_2O_3 nanoparticles indicating CFUs in *Escherichia coli* culture

Figure 12: Effects of Cr_2O_3 nanoparticles indicating CFUs in *Bacillus subtilis* culture

3.4 Mode of action of Cr_2O_3 nanoparticles against bacterial pathogens

In many cases, NPs are very bactericidal against pathogenic bacterial strains. Depending on the particle size, capping technique, and concentration, the metal nanoparticles can be either bactericidal or bacteriostatic (Slavin et al., 2017). There are many investigations that have shown the antibacterial activity of nanoparticles against gram-positive and gram-negative bacteria. The cell wall structure of gram-negative strain is characterized by the presence of a thin peptidoglycan layer (about 7–8 nm) having negative charges on its surface (Sirelkhatim et al., 2015). The antibacterial efficacy displayed by the NPs is tightly linked with these properties; the thin cell wall enables higher penetration of the NPs inside the bacterial cell and the negative surface charge of the NPs is responsible for a higher electrostatic interaction between the cells and NPs and thus leading to the production of ROS and oxidative stress. This results in the killing and suppression of bacteria (Mai-Prochnow et al., 2016; Pramanik et al., 2012). Unlike gram-negative bacteria, gram positive bacteria do not have a polysaccharide membrane with structural lipopolysaccharides, but only an outer peptidoglycan layer. This guarantees improved permeability for substances. The reduced negative surface charge allows nanoparticles penetration and allows negatively charged superoxide radical anions and peroxide ions to enter the cell, resulting in cell destruction at relatively low concentrations (Padmavathy & Vijayaraghavan, 2008) for gram-positive strains.

The nanoparticles that are less than 10 nanometers wide can pass through the cell wall of bacteria (Tamayo, Azócar, Kogan, Riveros, Páez, et al., 2016). Once they reach the cytoplasmic membrane, Cr_2O_3 NPs can enter the cytoplasm by being engulfed through endocytosis or by just moving across it (Hou et al., 2017). Cossart and Helenius reported that endocytosis is a fascinating process that occurs in cells when the cytoplasmic membrane wraps around things from outside the cell and pulls them inside in vesicles (Cossart & Helenius, 2014). Cr_2O_3 nanoparticles (NPs) can use this route to enter the cell (Figure 13), where they can be very close to the cell's inner workings. These nanoparticles may also travel directly into the cytoplasm, probably because they tend to stick to the membrane. This close encounter, along with the production of reactive oxygen species (ROS) on the nanoparticle surface, can weaken the membrane's defenses and allow the control of nanoparticles (Giannousi et al., 2017). Direct diffusion occurs when Cr_2O_3 nanoparticles look for and interact with important parts of the cytoplasmic membrane, such as the inviting

surfaces of lipid head groups or the flexible tails of phospholipids. The surface charge of these nanoparticles can be either positive or negative, which means that they are either attracted to or repelled by water, and so may interact with various parts of the membrane (Tamayo, Azócar, Kogan, Riveros, & Páez, 2016) . Lastly, after penetrating into the cytoplasm, the nanoparticles could interact with the DNA molecules, which could disrupt the helical structure. When nanoparticles enter the cytoplasm, they can interact with the DNA molecules and cause disruption in the helical structure, inhibit DNA replication and denature proteins. All such damages together cause loss of the important cellular functions and lead to the deaths of the cells (Giannousi et al., 2017) . Besides these mechanisms, Cr₂O₃ nanoparticles can also release copper ions at the same time, which can have a variety of toxic effects, as mentioned above. In addition to interacting with the cell, the interaction of nanoparticles with ion-mediated effects proceeds in parallel and enhances the overall antimicrobial activity (Román et al., 2020).

Figure 13: Mechanisms of Action of Nanoparticles Against Bacterial Pathogens

3.5 *Significance, limitations and future prospects of study*

Although the findings of this study are encouraging, there are some constraints that should be taken into consideration. The use of plant extracts in NP production could create size, shape and surface chemistry variations, as the bioactive phytochemical content varies, which may affect repeatability and consistency of antimicrobial effects. The green synthesis pathway is environmentally friendly, but is not scalable without compromising the homogeneity of the particles, yield, and stability. The antimicrobial testing performed in this study was limited to in vitro conditions, and further studies are necessary to investigate the in vivo toxicity, cytocompatibility and long-term stability of the nanoparticles, particularly in human bodies and beneficial microorganisms. Moreover, despite the high antibacterial activity reported, the proposed mechanisms of action, including membrane disruption, production of reactive oxygen species (ROS) and DNA damage have not been studied and should be further confirmed through extensive molecular and cellular investigations. The investigation of these pathways could give a better understanding of the therapeutic potential and biosafety of the Cr₂O₃ nanoparticles which are derived from *Ficus carica*. Future research should focus on the development of materials with these nanoparticles, like antimicrobial coatings, wound dressings, or water purification systems, as well as the lifecycle safety and environmental impact. These factors could be critical to the application of this green synthesis approach in real-world biomedical and environmental applications. The present research is important because it offers sustainable, economical and eco-friendly synthesis method for the preparation of chromium oxide (Cr₂O₃) nanoparticles using green extract from *Ficus carica*, a plant species which has great phytochemical potential, but is yet least explored for nanoparticle synthesis. In this method, the extracted fruit from *Ficus carica* is used as a reducing and capping agent in the conventional synthesis of *Ficus carica* nanoparticles without the use of toxic chemicals. The synthesized Cr₂O₃ nanoparticles showed strong antimicrobial properties against gram-negative (*Escherichia coli*) and gram-positive (*Bacillus subtilis*) bacteria and can thus be used as good alternative antimicrobial agents against antibiotic resistant disease.

Conclusions

The results of this research show a novel and eco-friendly synthesis method of highly crystalline nanoparticles of Cr_2O_3 using *Ficus carica* fruit extract, combining sustainability with therapeutic functionality. The antimicrobial activities of the phytochemical capped nanoparticles exhibited an exclusive property when it came to the diameters of the zones of inhibition and the speed at which the bacteria was eradicated, in comparison to the crude extracts and standard antibiotics. The bioactive phytoconstituents also played a role in the dual mechanism, ROS generation and membrane destabilization, thus providing a powerful bactericidal strategy against both gram-positive and gram-negative pathogens. Interestingly these results not only support the higher efficiency of *F. carica* based Cr_2O_3 -NPs over other plant based systems reported so far, but also point towards their prospective use as future nanobiotics. This work is a good proof of concept but needs to be extended by further in vivo toxicity and pharmacokinetics studies, as well as application-based integration into biomedical devices or antimicrobial coatings. In summary, this work can be considered as a contribution to the field of green nanotechnology, providing a scalable, biocompatible and effective platform to combat antibiotic resistance, and new opportunities for the use of phytofunctionalized nanomaterials in translational medicine. Furthermore, due to the variety of biomedical and environmental applications of them, the use of these nanoparticles can yield solutions to the worldwide health problems. Their ability to kill bacteria indicates that they could also be used in other food preservation, water purification and surface disinfection applications as well as therapeutics. Consequently, the metabolites of *F. carica* have the advantage over conventional chemical methods to enhance the stability of nanoparticles and to reduce their toxicity. In summary materials, scientists, microbiologist and pharmacologist will work together to develop a more efficient drug based on interdisciplinary research. The future of interdisciplinary studies in the area of pharmacology, microbiology and material science is promising as the three areas are working together to create better drugs. The present work can be used as a template for future nanobiotechnology research for the creation of an effective tool to combat the MDR.

Statements of Declarations

Conflict of Interest

All authors declare that they haven't any conflict of interest in the publication of this research work in the journal.

Acknowledgment

All authors are like to express their gratitude support by the labs staff of the Department, University of Education, Lahore Pakistan

Funding Declaration

No funding for OA publication

Ethics Declaration

Not Applicable

References

- Ahmed Mohamed, H. E., Afridi, S., Khalil, A. T., Zohra, T., Ali, M., Alam, M. M., Ikram, A., Shinwari, Z. K., & Maaza, M. (2020a). Phyto-fabricated Cr₂O₃ nanoparticle for multifunctional biomedical applications. *Nanomedicine*, 15(17), 1653-1669.
- Ahmed Mohamed, H. E., Afridi, S., Khalil, A. T., Zohra, T., Ali, M., Alam, M. M., Ikram, A., Shinwari, Z. K., & Maaza, M. J. N. (2020b). Phyto-fabricated Cr₂O₃ nanoparticle for multifunctional biomedical applications. *15*(17), 1653-1669.
- Ajitha, B., Reddy, Y. A. K., & Reddy, P. S. (2015). Green synthesis and characterization of silver nanoparticles using *Lantana camara* leaf extract. *Materials science and engineering: C*, 49, 373-381.
- Alarifi, S., Ali, D., & Alkahtani, S. J. I. j. o. n. (2016). Mechanistic investigation of toxicity of chromium oxide nanoparticles in murine fibrosarcoma cells. 1253-1259.
- Anandhi, J., Rayer, S., Chithambarathanu, T. J. C., & Engineering, M. (2017). Synthesis, FTIR studies and optical properties of aluminium doped chromium oxide nanoparticles by microwave irradiation at different concentrations. 5(2), 43.
- Badgujar, S. B., Patel, V. V., Bandivdekar, A. H., & Mahajan, R. T. J. P. b. (2014). Traditional uses, phytochemistry and pharmacology of *Ficus carica*: A review. 52(11), 1487-1503.
- Barzinjy, A. A., & Azeez, H. H. (2020). Green synthesis and characterization of zinc oxide nanoparticles using *Eucalyptus globulus* Labill. leaf extract and zinc nitrate hexahydrate salt. *SN Applied Sciences*, 2(5), 991.
- Behzadi, S., Ghasemi, F., Ghalkhani, M., Ashkarran, A. A., Akbari, S. M., Pakpour, S., Hormozi-Nezhad, M. R., Jamshidi, Z., Mirsadeghi, S., & Dinarvand, R. (2015). Determination of nanoparticles using UV-Vis spectra. *Nanoscale*, 7(12), 5134-5139.
- Bokuniaeve, A., & Vorokh, A. (2019). Estimation of particle size using the Debye equation and the Scherrer formula for polyphasic TiO₂ powder. *journal of physics: Conference series*,
- Cheah, S.-Y., Aminuzzaman, M., Phang, Y.-K., Lim, S. C.-Y., Koh, M.-X., Djearmane, S., Subramaniam, H., Lim, B.-H., Li, F., & Wong, L.-S. (2025). Green-synthesized chromium oxide nanoparticles using pomegranate husk extract: multifunctional bioactivity in antioxidant potential, lipase and amylase inhibition, and cytotoxicity. *Green Processing and Synthesis*, 14(1), 20240246.
- Cossart, P., & Helenius, A. (2014). Endocytosis of viruses and bacteria. *Cold Spring Harbor perspectives in biology*, 6(8), a016972.
- Dueñas, M., Pérez-Alonso, J. J., Santos-Buelga, C., & Escribano-Bailón, T. (2008). Anthocyanin composition in fig (*Ficus carica* L.). *Journal of Food Composition and Analysis*, 21(2), 107-115.
- Dueñas, M., Pérez-Alonso, J. J., Santos-Buelga, C., Escribano-Bailón, T. J. J. o. F. C., & Analysis. (2008). Anthocyanin composition in fig (*Ficus carica* L.). 21(2), 107-115.
- Giannousi, K., Pantazaki, A., & Dendrinou-Samara, C. (2017). Copper-based nanoparticles as antimicrobials. In *Nanostructures for antimicrobial therapy* (pp. 515-529). Elsevier.
- Goel, M., Sharma, A., & Sharma, B. J. S. C. (2023). Recent advances in biogenic silver nanoparticles for their biomedical applications. 4(1), 61-94.
- Gour, A., Jain, N. K. J. A. c., nanomedicine,, & biotechnology. (2019). Advances in green synthesis of nanoparticles. 47(1), 844-851.
- Hou, J., Wang, X., Hayat, T., & Wang, X. J. E. p. (2017). Ecotoxicological effects and mechanism of CuO nanoparticles to individual organisms. 221, 209-217.
- Iqbal, J., Abbasi, B. A., Munir, A., Uddin, S., Kanwal, S., & Mahmood, T. (2020). Facile green synthesis approach for the production of chromium oxide nanoparticles and their different in vitro biological activities. *Microscopy research and technique*, 83(6), 706-719.

- Iqbal, J., Abbasi, B. A., Munir, A., Uddin, S., Kanwal, S., Mahmood, T. J. M. r., & technique. (2020). Facile green synthesis approach for the production of chromium oxide nanoparticles and their different in vitro biological activities. *83*(6), 706-719.
- Isacfranklin, M., Ameen, F., Ravi, G., Yuvakkumar, R., Hong, S., Velauthapillai, D., Thambidurai, M., & Dang, C. (2020). Single-phase Cr₂O₃ nanoparticles for biomedical applications. *Ceramics International*, *46*(12), 19890-19895.
- Jadoun, S., Arif, R., Jangid, N. K., & Meena, R. K. J. E. C. L. (2021). Green synthesis of nanoparticles using plant extracts: A review. *19*(1), 355-374.
- Joshi, Y., Joshi, A. K., Prasad, N., & Juyal, D. (2014). A review on Ficus palmata (wild himalayan fig). *The journal of phytopharmacology*, *3*(5), 374-377.
- Kasprzak, M. M., Erxleben, A., & Ochocki, J. (2015). Properties and applications of flavonoid metal complexes. *Rsc Advances*, *5*(57), 45853-45877.
- Khan, S. A., Shahid, S., Hanif, S., Almoallim, H. S., Alharbi, S. A., & Sellami, H. (2021). Green synthesis of chromium oxide nanoparticles for antibacterial, antioxidant anticancer, and biocompatibility activities. *International Journal of Molecular Sciences*, *22*(2), 502.
- Khan, S. A., Shahid, S., & Lee, C.-S. J. B. (2020). Green synthesis of gold and silver nanoparticles using leaf extract of Clerodendrum inerme; characterization, antimicrobial, and antioxidant activities. *10*(6), 835.
- Khan, S. A., Shahid, S., Shahid, B., Fatima, U., & Abbasi, S. A. (2020a). Green synthesis of MnO nanoparticles using abutilon indicum leaf extract for biological, photocatalytic, and adsorption activities. *Biomolecules*, *10*(5), 785.
- Khan, S. A., Shahid, S., Shahid, B., Fatima, U., & Abbasi, S. A. J. B. (2020b). Green synthesis of MnO nanoparticles using abutilon indicum leaf extract for biological, photocatalytic, and adsorption activities. *10*(5), 785.
- Kumar, A., Singh, K. R., Ghate, M. D., Lahlhenmawia, H., Kumar, D., & Singh, J. (2022). Bioinspired quantum dots for cancer therapy: A mini-review. *Materials Letters*, *313*, 131742.
- Lodhi, F., Bradley, M. V., & Crane, J. C. J. P. P. (1969). Auxins and gibberellin-like substances in parthenocarpic and non-parthenocarpic syconia of Ficus carica L., cv. King. *44*(4), 555-561.
- Mai-Prochnow, A., Clauson, M., Hong, J., & Murphy, A. B. (2016). Gram positive and Gram negative bacteria differ in their sensitivity to cold plasma. *Scientific reports*, *6*(1), 38610.
- Masadeh, M. M., Karasneh, G. A., Al-Akhras, M. A., Albiss, B. A., Aljarah, K. M., Al-Azzam, S. I., & Alzoubi, K. H. (2015). Cerium oxide and iron oxide nanoparticles abolish the antibacterial activity of ciprofloxacin against gram positive and gram negative biofilm bacteria. *Cytotechnology*, *67*(3), 427-435.
- Mawa, S., Husain, K., & Jantan, I. (2013). Ficus carica L.(Moraceae): phytochemistry, traditional uses and biological activities. *Evidence-Based Complementary and Alternative Medicine*, *2013*(1), 974256.
- Mohan, A. C., & Renjanadevi, B. (2016). Preparation of zinc oxide nanoparticles and its characterization using scanning electron microscopy (SEM) and X-ray diffraction (XRD). *Procedia Technology*, *24*, 761-766.
- Moloudizargari, M., Mikaili, P., Aghajanshakeri, S., Asghari, M. H., & Shayegh, J. J. P. r. (2013). Pharmacological and therapeutic effects of Peganum harmala and its main alkaloids. *7*(14), 199.
- Musaeva, N., Shukla, M. K., Kumar, D., & Azizov, I. (2021). Influence of Sesame oil immunogenesis and hemopoiesis in imuran induced immunodeficiency. *Pharmacologyonline*, *3*, 1544-1550.
- Nigam, A., Saini, S., Rai, A. K., & Pawar, S. (2021). Structural, optical, cytotoxicity, and antimicrobial properties of MgO, ZnO and MgO/ZnO nanocomposite for biomedical applications. *Ceramics International*, *47*(14), 19515-19525.
- Niroumand, M. C., Farzaei, M. H., & Amin, G. J. J. o. T. C. M. (2015). Medicinal properties of Peganum harmala L. in traditional Iranian medicine and modern phytotherapy: a review. *35*(1), 104-109.
- Oliveira, A. P., Silva, L. R., Andrade, P. B., Valentão, P., Silva, B. M., Goncalves, R. F., Pereira, J. A., & Guedes de Pinho, P. (2010). Further insight into the latex metabolite profile of Ficus carica. *Journal of Agricultural and Food Chemistry*, *58*(20), 10855-10863.
- Oliveira, A. P., Silva, L. R., Andrade, P. B., Valentao, P., Silva, B. M., Goncalves, R. F., Pereira, J. A., Guedes de Pinho, P. J. J. o. A., & Chemistry, F. (2010). Further insight into the latex metabolite profile of Ficus carica. *58*(20), 10855-10863.
- Oliveira, A. P., Valentão, P., Pereira, J. A., Silva, B. M., Tavares, F., & Andrade, P. B. (2009). Ficus carica L.: Metabolic and biological screening. *Food and Chemical Toxicology*, *47*(11), 2841-2846.
- Onyebuchi, C., & Kavaz, D. J. S. r. (2020). Effect of extraction temperature and solvent type on the bioactive potential of Ocimum gratissimum L. extracts. *10*(1), 21760.
- Padmavathy, N., & Vijayaraghavan, R. (2008). Enhanced bioactivity of ZnO nanoparticles—an antimicrobial study. *Science and technology of advanced materials*.

- Park, Y., Hong, Y., Weyers, A., Kim, Y., & Linhardt, R. (2011). Polysaccharides and phytochemicals: a natural reservoir for the green synthesis of gold and silver nanoparticles. *IET nanobiotechnology*, 5(3), 69-78.
- Parveen, K., Banse, V., & Ledwani, L. (2016). Green synthesis of nanoparticles: Their advantages and disadvantages. AIP conference proceedings,
- Parvekar, P., Palaskar, J., Metgud, S., Maria, R., & Dutta, S. J. B. i. i. d. (2020). The minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) of silver nanoparticles against *Staphylococcus aureus*. 7(1), 105-109.
- Patle, T. K., Shrivastava, K., Kurrey, R., Upadhyay, S., Jangde, R., & Chauhan, R. (2020). Phytochemical screening and determination of phenolics and flavonoids in *Dillenia pentagyna* using UV-vis and FTIR spectroscopy. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 242, 118717.
- Pramanik, A., Laha, D., Bhattacharya, D., Pramanik, P., & Karmakar, P. (2012). A novel study of antibacterial activity of copper iodide nanoparticle mediated by DNA and membrane damage. *Colloids and Surfaces B: Biointerfaces*, 96, 50-55.
- Prashanth, G., Prashanth, P., Nagabhushana, B., Ananda, S., Krishnaiah, G., Nagendra, H., Sathyananda, H., Rajendra Singh, C., Yogisha, S., & Anand, S. (2018). Comparison of anticancer activity of biocompatible ZnO nanoparticles prepared by solution combustion synthesis using aqueous leaf extracts of *Abutilon indicum*, *Melia azedarach* and *Indigofera tinctoria* as biofuels. *Artificial cells, nanomedicine, and biotechnology*, 46(5), 968-979.
- Ps, P., & Ks, T. (2017). Antioxidant, antibacterial and cytotoxic potential of silver nanoparticles synthesized using terpenes rich extract of *Lantana camara* L. leaves. *Biochemistry and biophysics reports*, 10, 76-81.
- Rakshit, S., Jana, P. C., & Kamilya, T. J. C. N. (2023). Green synthesis of copper nanoparticles by using plant extracts and their biomedical applications—an extensive review. 8(2), 110-125.
- Ramesh, C., Mohan Kumar, K., Latha, N., & Ragunathan, V. J. C. N. (2012). Green synthesis of Cr₂O₃ nanoparticles using *Tridax procumbens* leaf extract and its antibacterial activity on *Escherichia coli*. 8(4), 603-607.
- Rao, V. R., Patil, K. T., Kumar, D., Gupta, M. K., & Shin, D.-S. J. R. i. C. (2022). Mild and efficient one-pot synthesis of (E)-styrylperfluoroalkyl ketone from styrene. 4, 100260.
- Román, L. E., Gomez, E. D., Solís, J. L., & Gómez, M. M. (2020). Antibacterial cotton fabric functionalized with copper oxide nanoparticles. *Molecules*, 25(24), 5802.
- Sangwan, P., & Kumar, H. (2017). Synthesis, characterization, and antibacterial activities of chromium oxide nanoparticles against *Klebsiella pneumoniae*. *Asian J. Pharm. Clin. Res*, 10(2), 207-209.
- Saod, W. M., Al-Janaby, M. S., Gayadh, E. W., Ramizy, A., & Hamid, L. L. (2024). Biogenic synthesis of iron oxide nanoparticles using *Hibiscus sabdariffa* extract: Potential for antibiotic development and antibacterial activity against multidrug-resistant bacteria. *Current Research in Green and Sustainable Chemistry*, 8, 100397. <https://doi.org/https://doi.org/10.1016/j.crgsc.2024.100397>
- Saranya, D., & Sekar, J. (2016). GC-MS and FT-IR Analyses of Ethylacetate Leaf extract of *Abutilon indicum* (L.) Sweet. *Int. J. Adv. Res. Biol. Sci*, 3(2), 193-197.
- Saritha, G. N. G., Anju, T., Kumar, A. J. J. o. A., & Research, F. (2022). Nanotechnology-Big impact: How nanotechnology is changing the future of agriculture? , 10, 100457.
- Singh, G., Kumar, D., & Dash, A. K. (2021). *Pinus gerardiana* Wallich ex. D. Don.-a review. *Phytomedicine plus*, 1(2), 100024.
- Singh, P., Kim, Y.-J., Zhang, D., & Yang, D.-C. (2016). Biological synthesis of nanoparticles from plants and microorganisms. *Trends in biotechnology*, 34(7), 588-599.
- Sirelkhatim, A., Mahmud, S., Seeni, A., Kaus, N. H. M., Ann, L. C., Bakhori, S. K. M., Hasan, H., & Mohamad, D. (2015). Review on zinc oxide nanoparticles: antibacterial activity and toxicity mechanism. *Nano-micro letters*, 7(3), 219-242.
- Slavin, Y. N., Asnis, J., Häfeli, U. O., & Bach, H. (2017). Metal nanoparticles: understanding the mechanisms behind antibacterial activity. *Journal of nanobiotechnology*, 15(1), 65.
- Soni, N., Mehta, S., Satpathy, G., & Gupta, R. K. (2014). Estimation of nutritional, phytochemical, antioxidant and antibacterial activity of dried fig (*Ficus carica*). *Journal of Pharmacognosy and Phytochemistry*, 3(2), 158-165.
- Tamayo, L., Azócar, M., Kogan, M., Riveros, A., & Páez, M. (2016). Copper-polymer nanocomposites: An excellent and cost-effective biocide for use on antibacterial surfaces. *Materials science and engineering: C*, 69, 1391-1409.
- Tamayo, L., Azócar, M., Kogan, M., Riveros, A., Páez, M. J. M. S., & C, E. (2016). Copper-polymer nanocomposites: An excellent and cost-effective biocide for use on antibacterial surfaces. 69, 1391-1409.

- Tang, S., Mao, C., Liu, Y., Kelly, D. Q., & Banerjee, S. K. (2007). Protein-mediated nanocrystal assembly for flash memory fabrication. *IEEE transactions on electron devices*, 54(3), 433-438.
- Thakkar, K. N., Mhatre, S. S., & Parikh, R. Y. (2010). Biological synthesis of metallic nanoparticles. *Nanomedicine: nanotechnology, biology and medicine*, 6(2), 257-262.

Figures

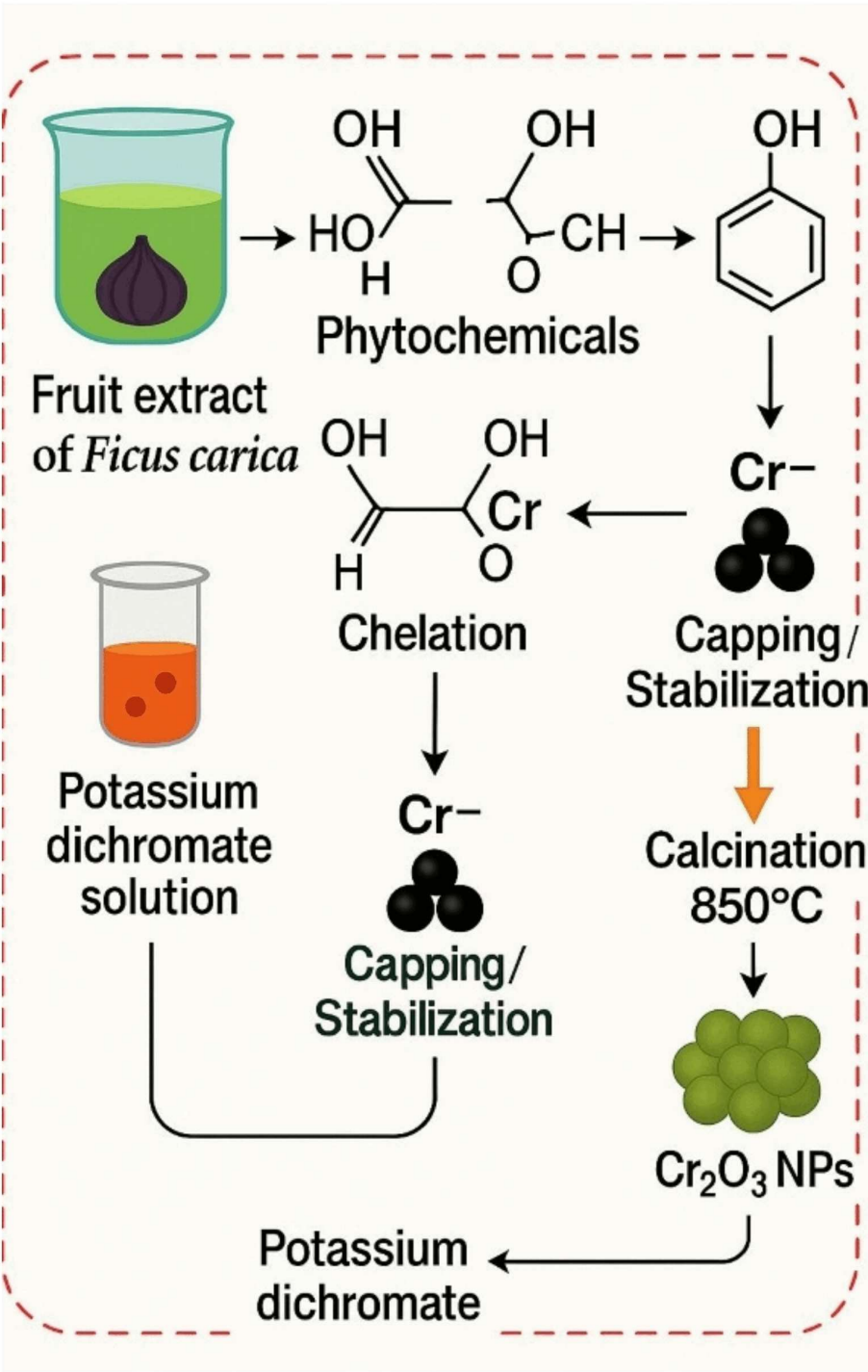


Figure 1

Mechanism of pathways of synthesis of Cr_2O_3 nanoparticles from *Ficus carica* Fruit extract

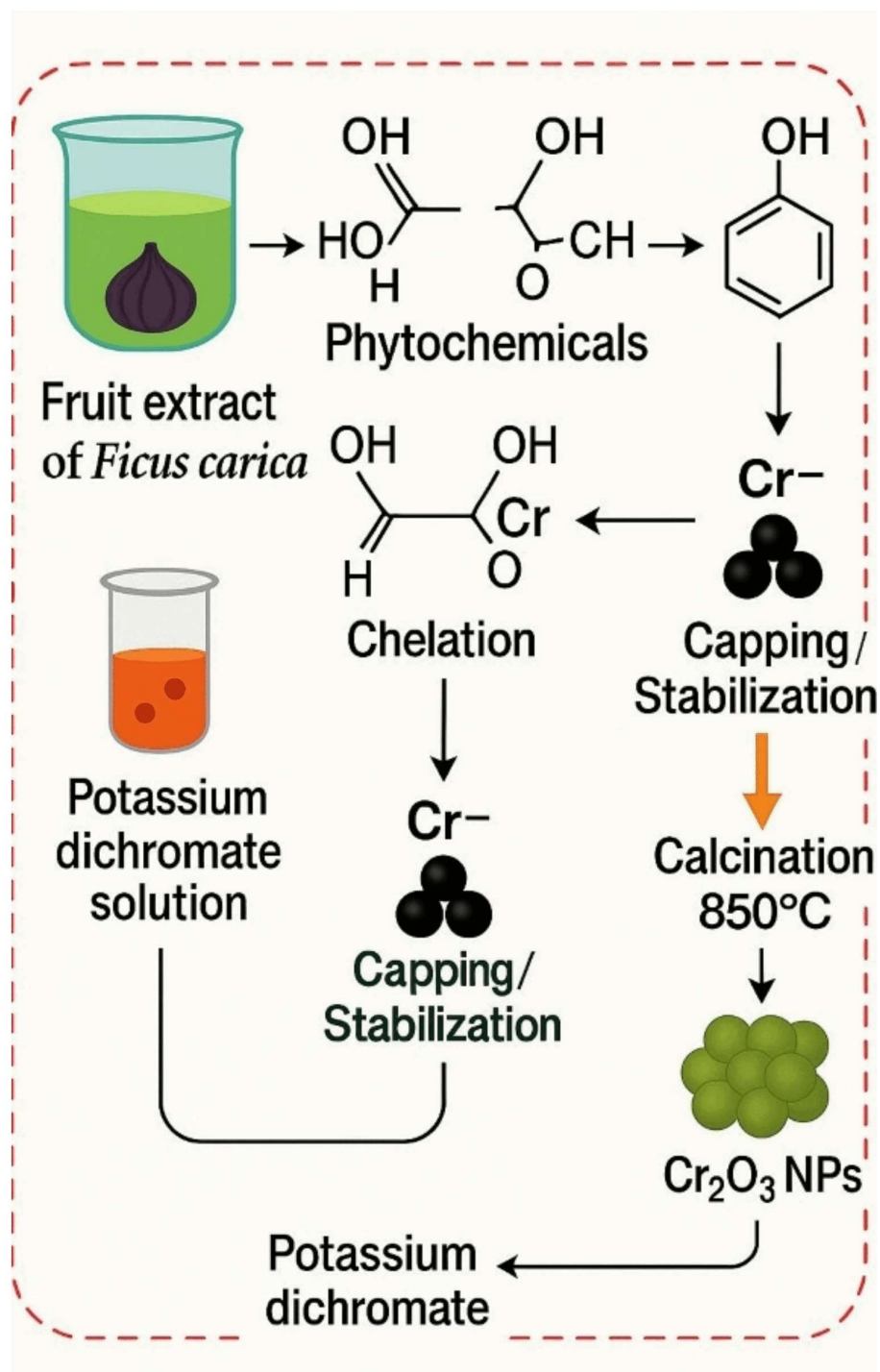


Figure 1

Mechanism of pathways of synthesis of Cr_2O_3 nanoparticles from *Ficus carica* Fruit extract

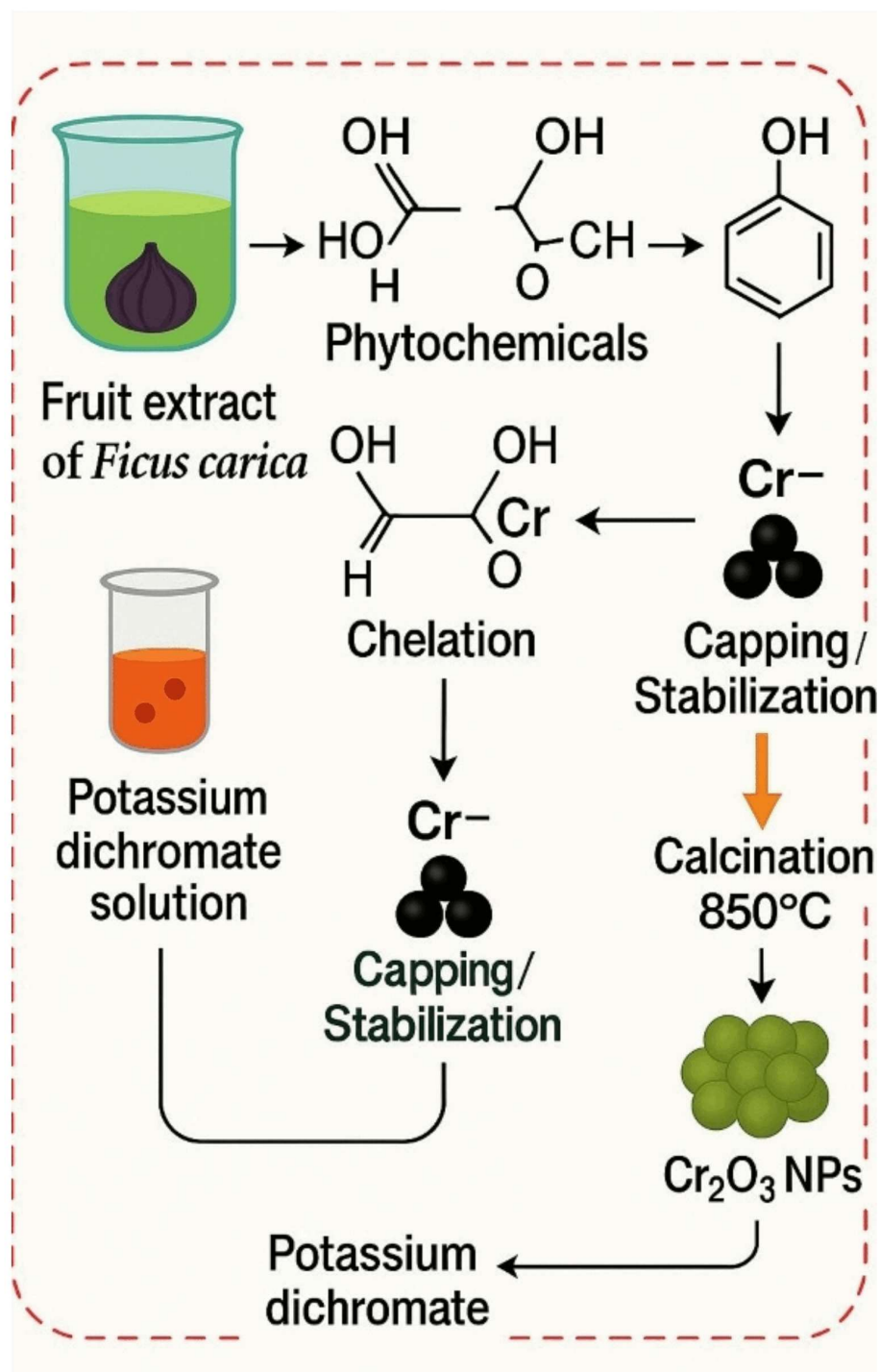


Figure 1

Mechanism of pathways of synthesis of Cr_2O_3 nanoparticles from *Ficus carica* Fruit extract

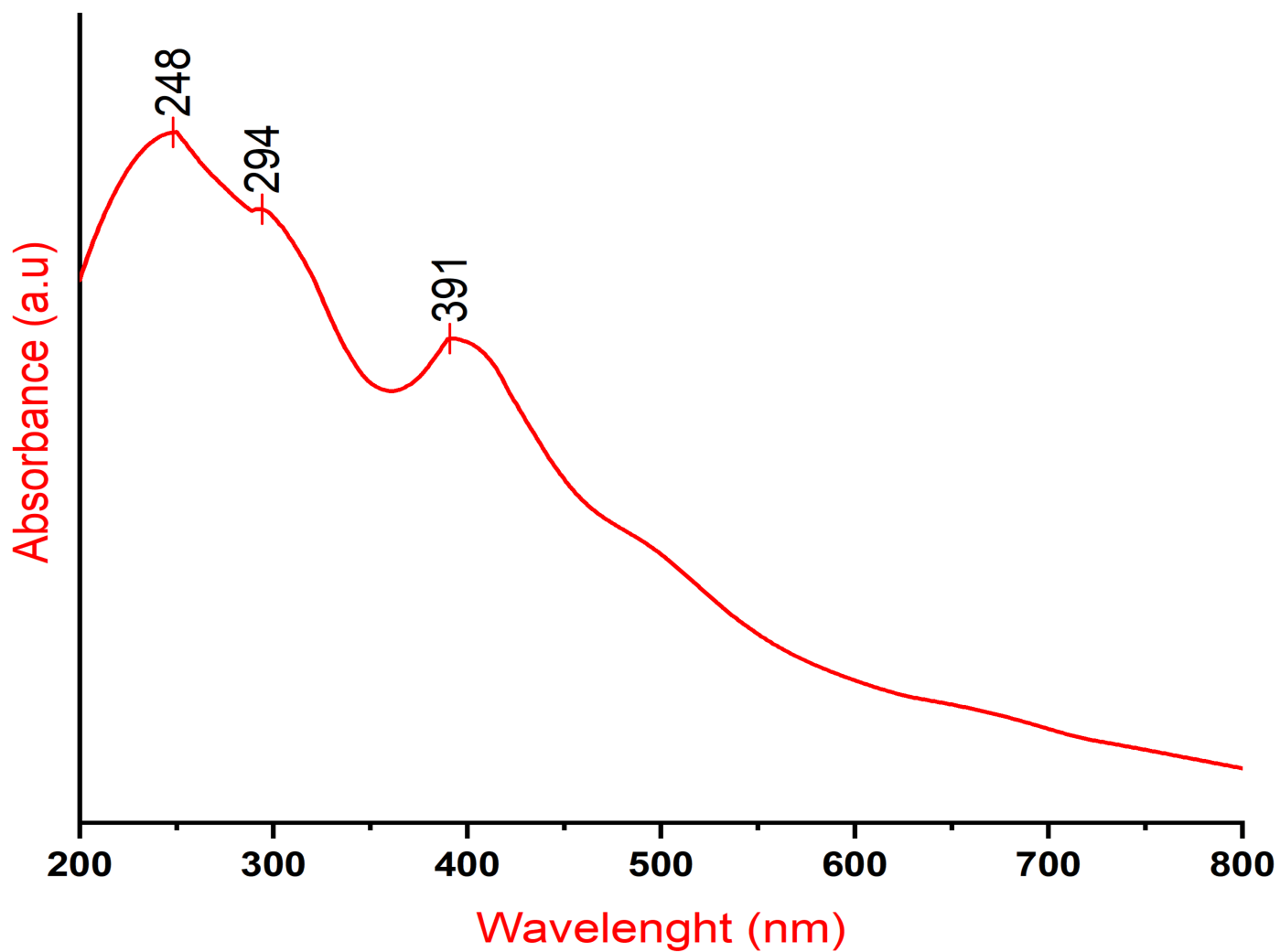


Figure 2

UV-visible spectrograms of *Ficus carica* Fruit extract

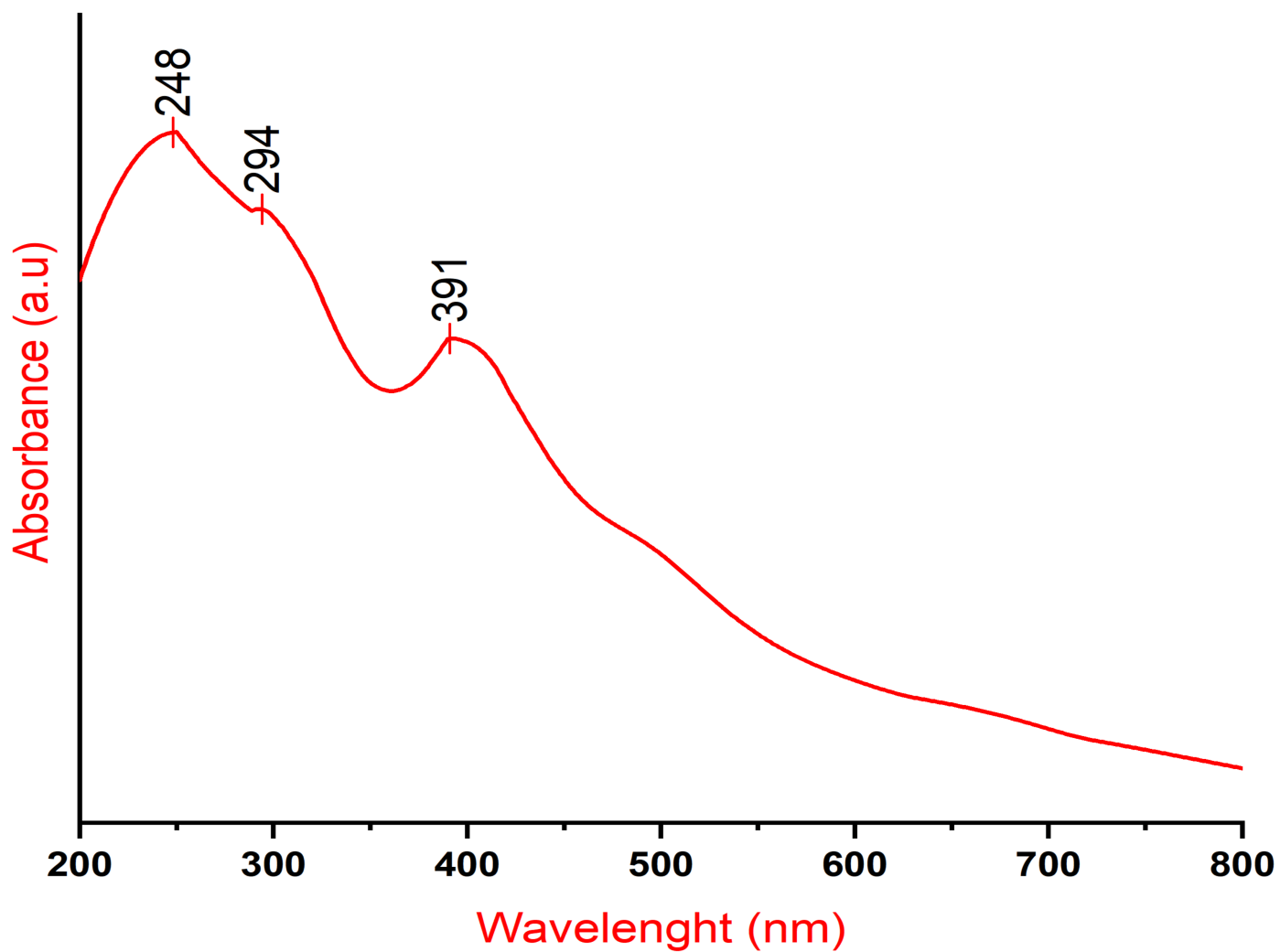


Figure 2

UV-visible spectrograms of *Ficus carica* Fruit extract

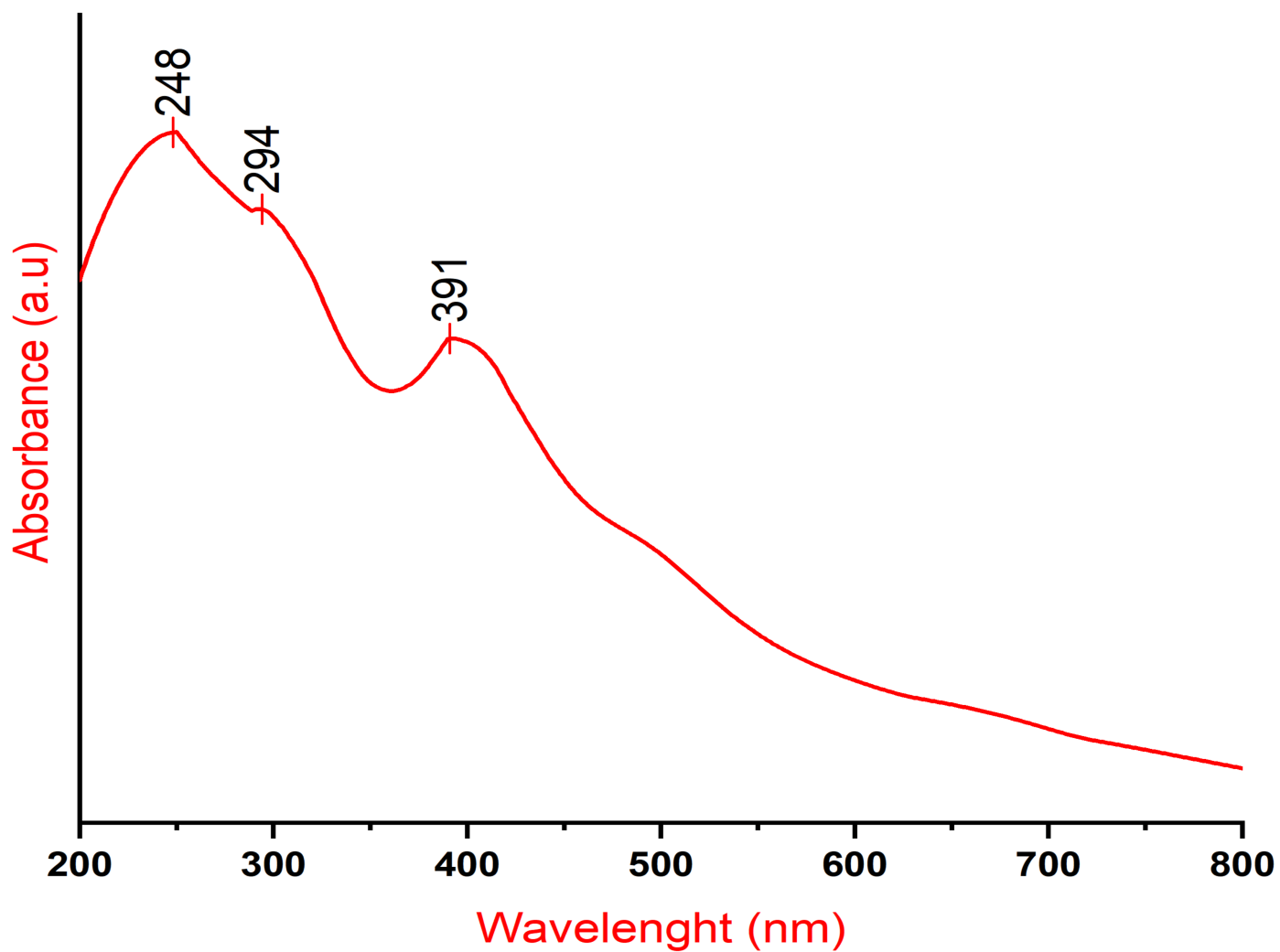


Figure 2

UV-visible spectrograms of *Ficus carica* Fruit extract

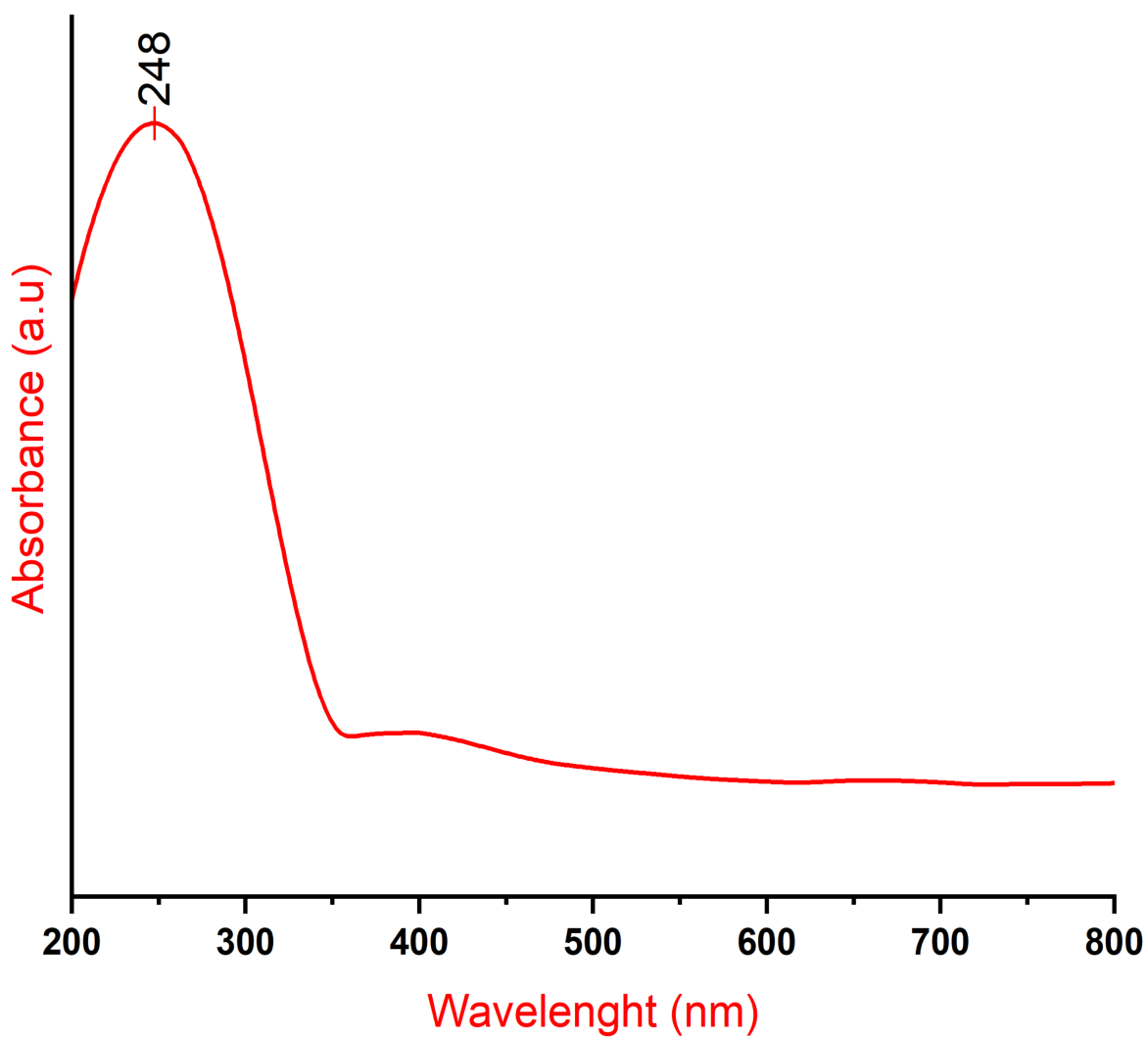


Figure 3

UV-visible spectrograms of Cr_2O_3 NPs through *Ficus carica* Fruit extract

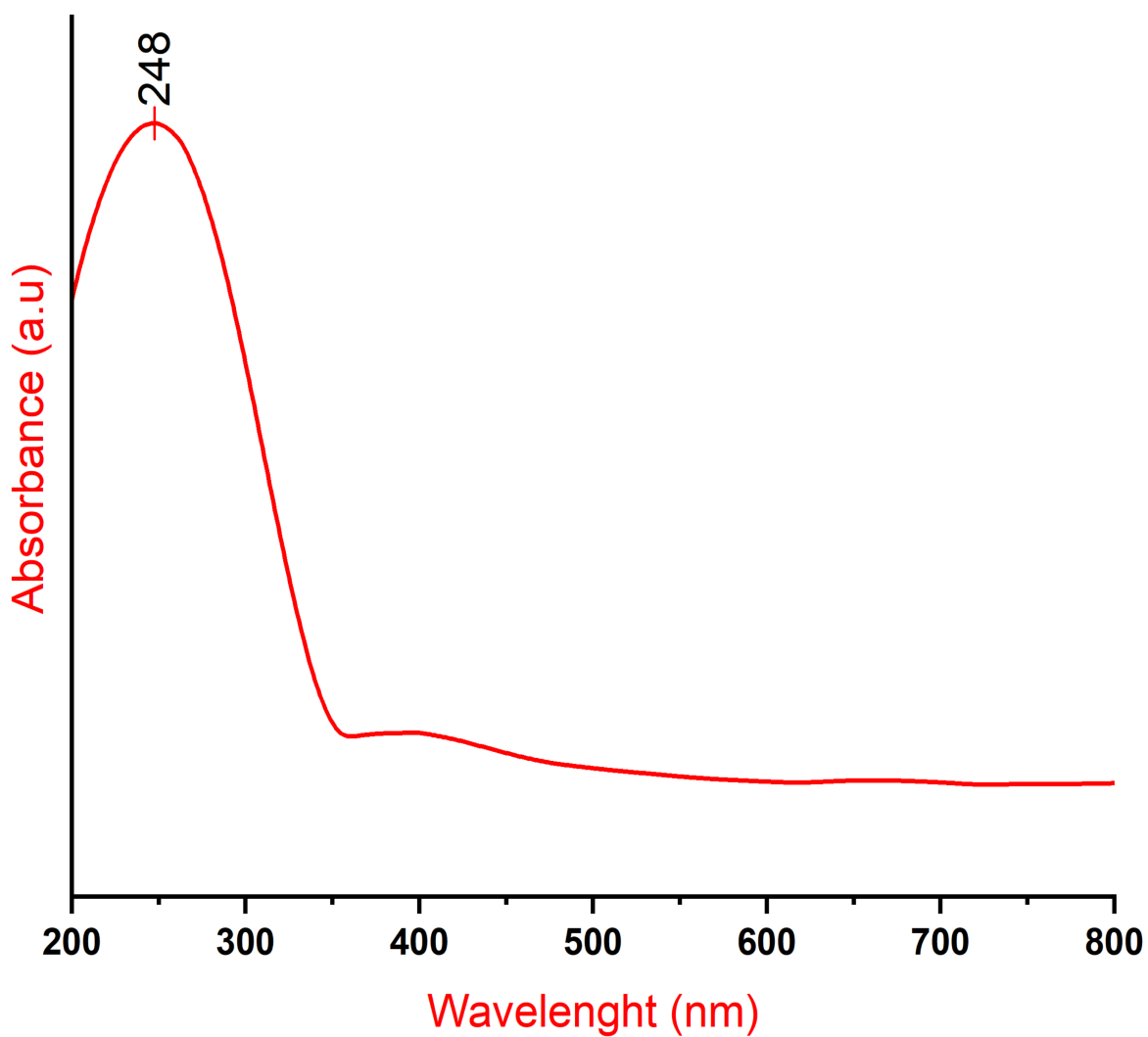


Figure 3

UV-visible spectrograms of Cr_2O_3 NPs through *Ficus carica* Fruit extract

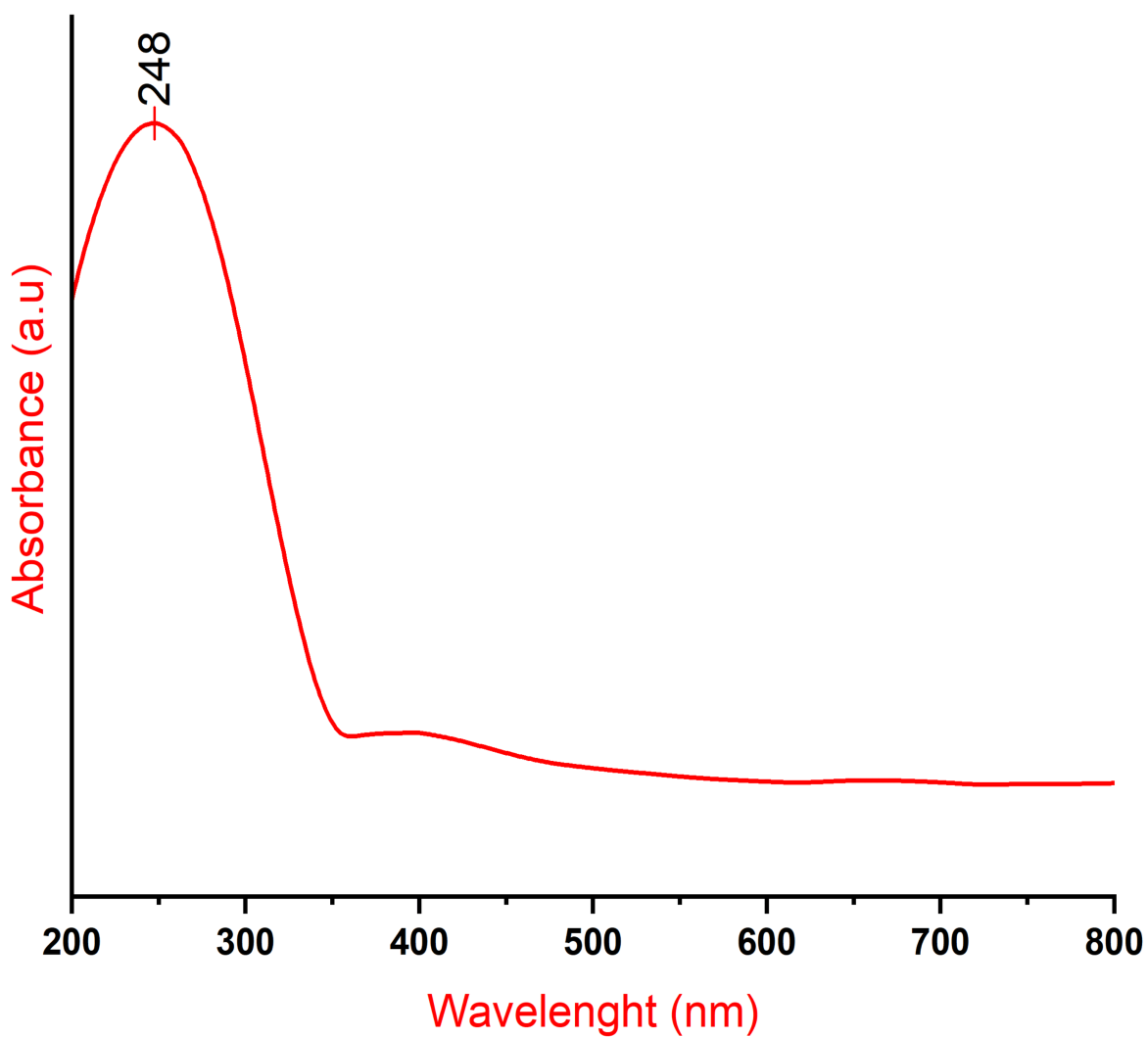


Figure 3

UV-visible spectrograms of Cr_2O_3 NPs through *Ficus carica* Fruit extract

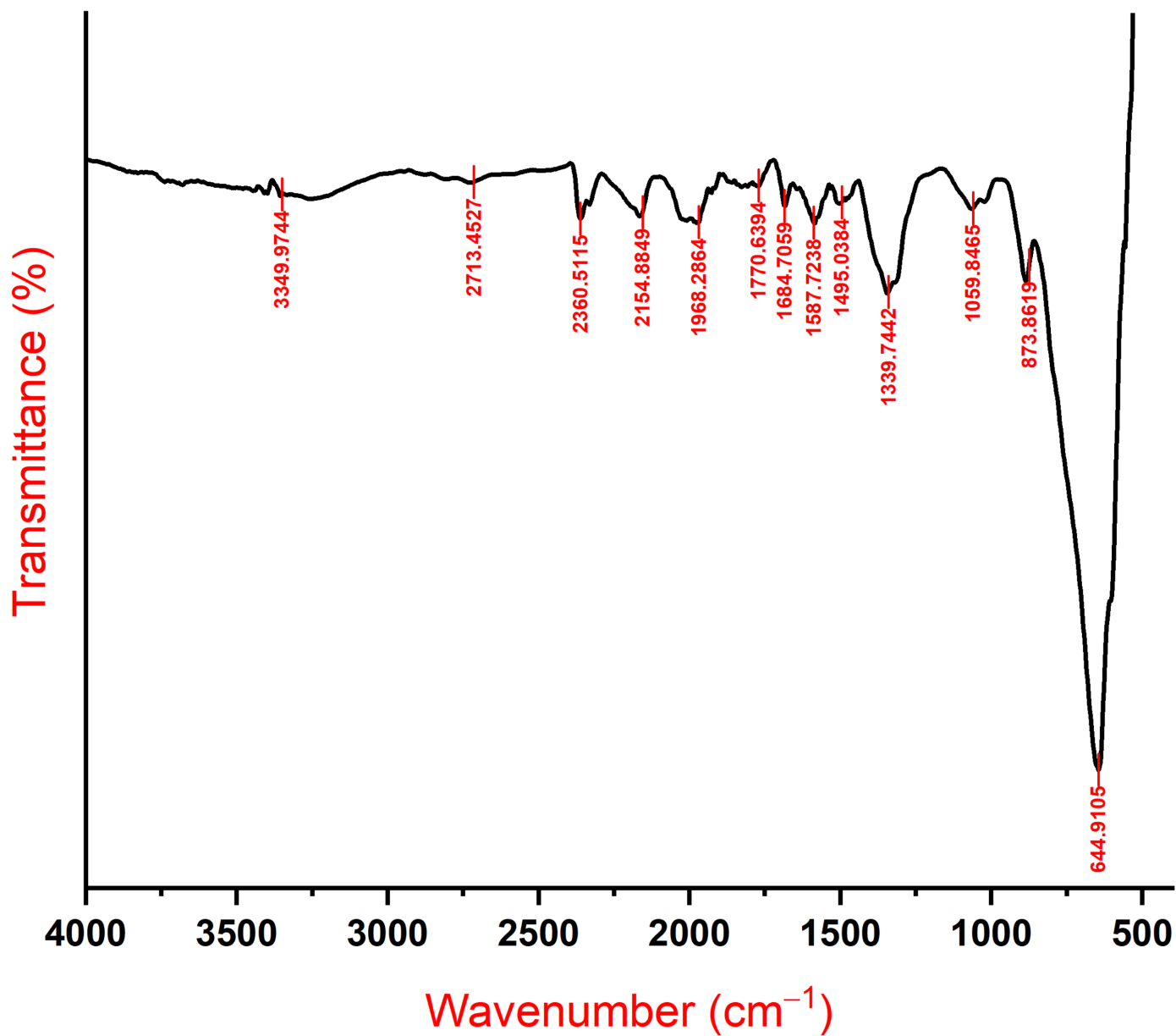


Figure 4

FT-IR spectrograms of *Ficus carica* fruit extract

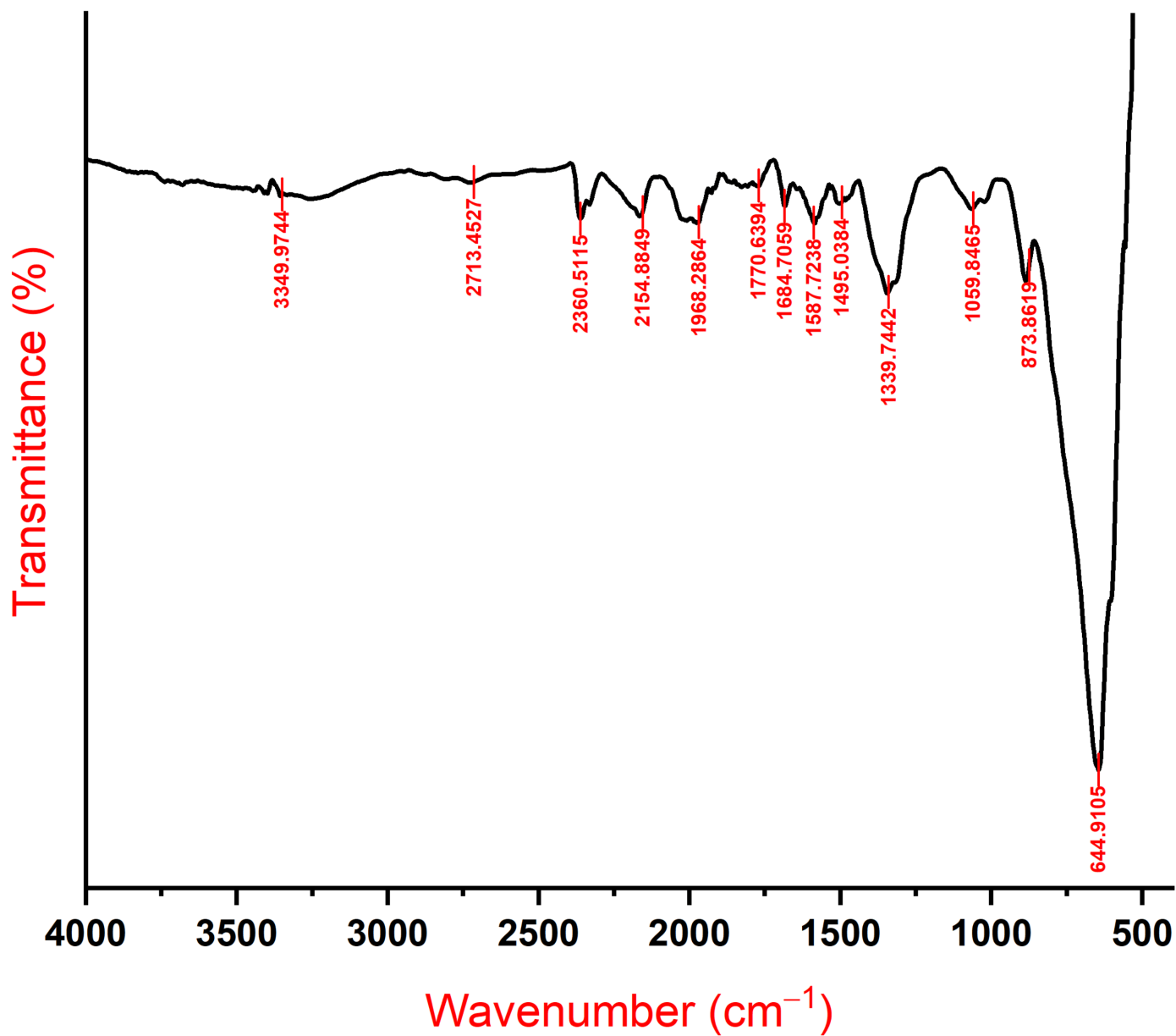


Figure 4

FT-IR spectrograms of *Ficus carica* fruit extract

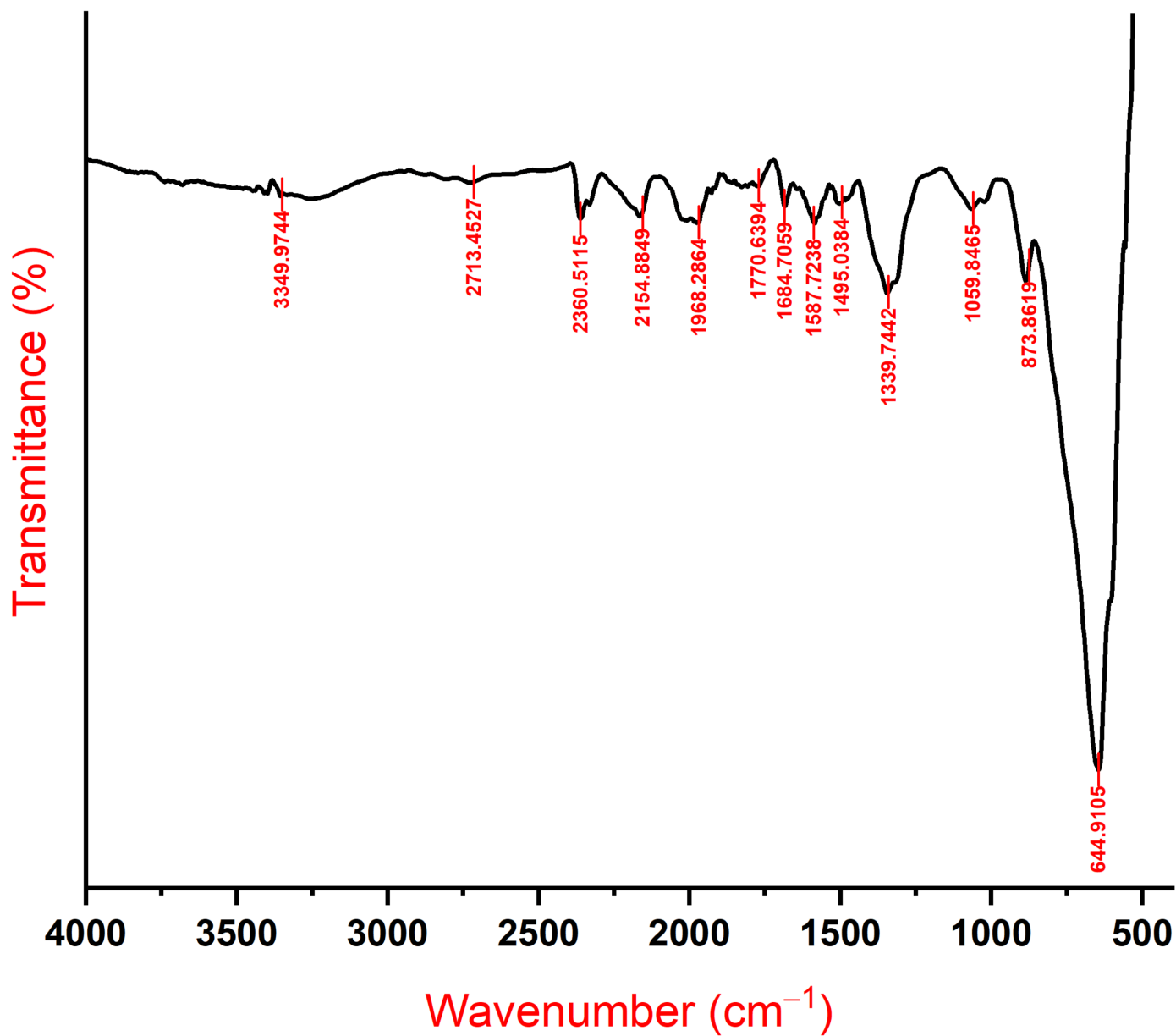


Figure 4

FT-IR spectrograms of *Ficus carica* fruit extract

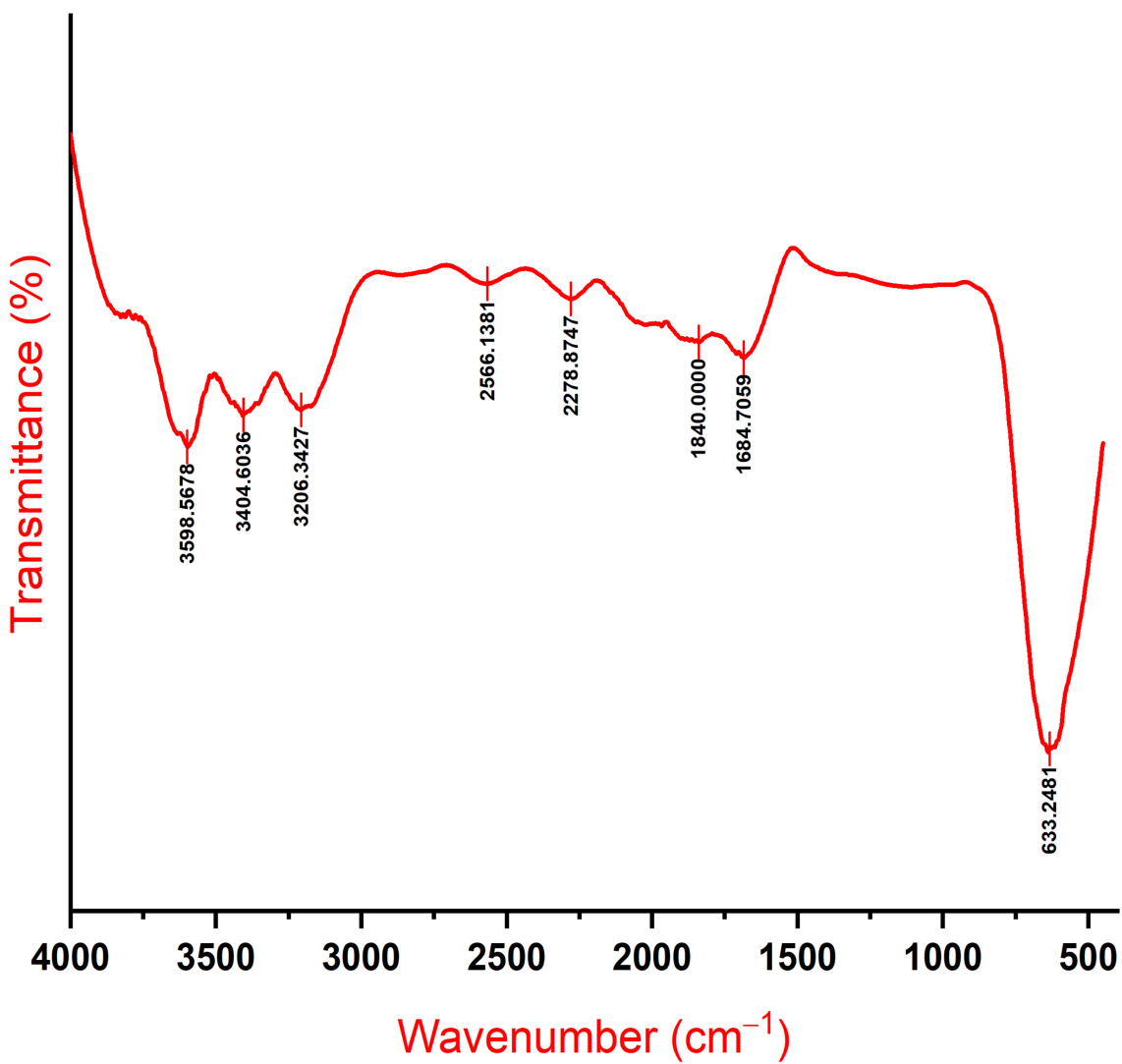


Figure 5

FT-IR spectrograms of Cr₂O₃ synthesis from *Ficus carica* fruit extract

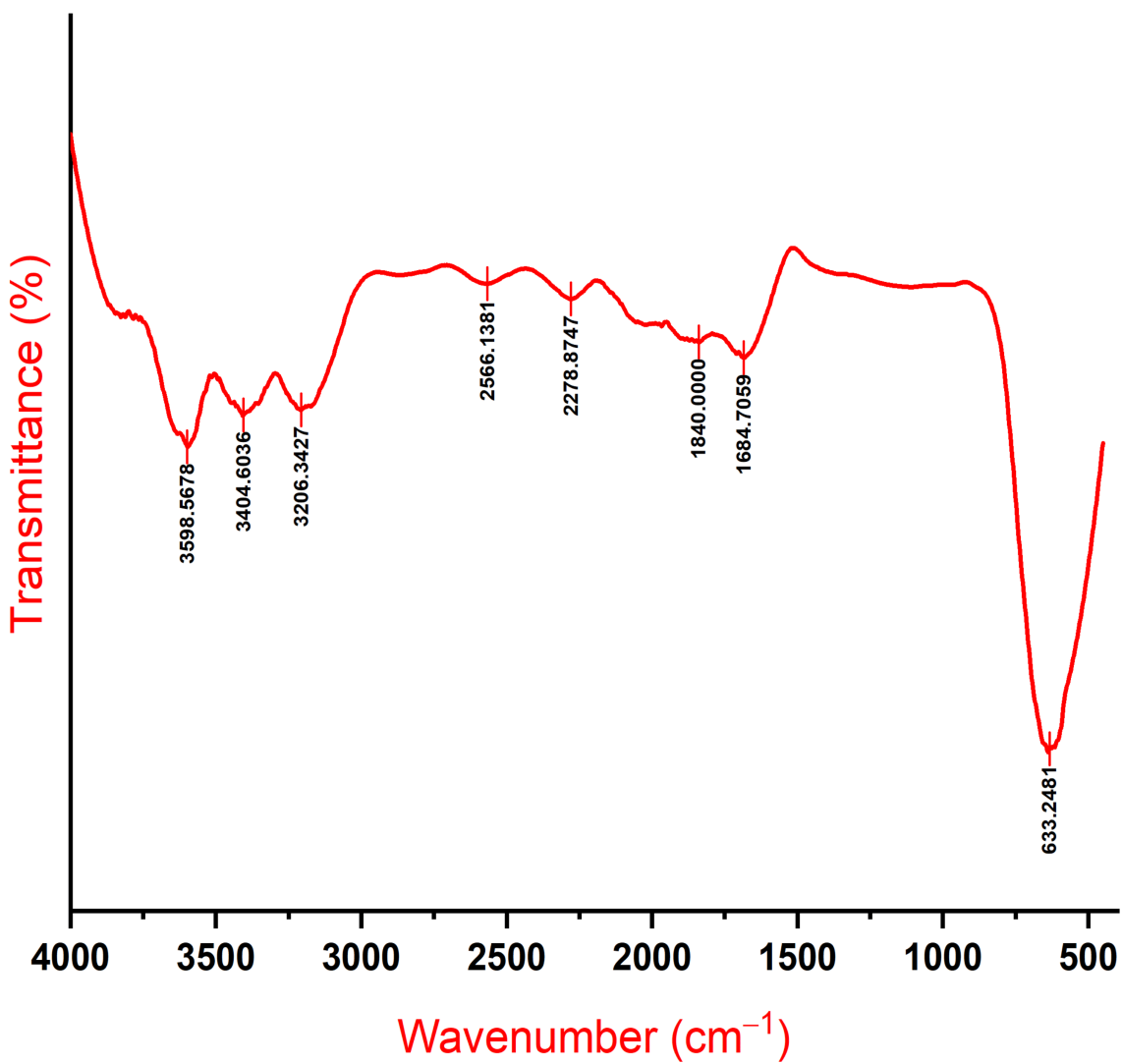


Figure 5

FT-IR spectrograms of Cr_2O_3 synthesis from *Ficus carica* fruit extract

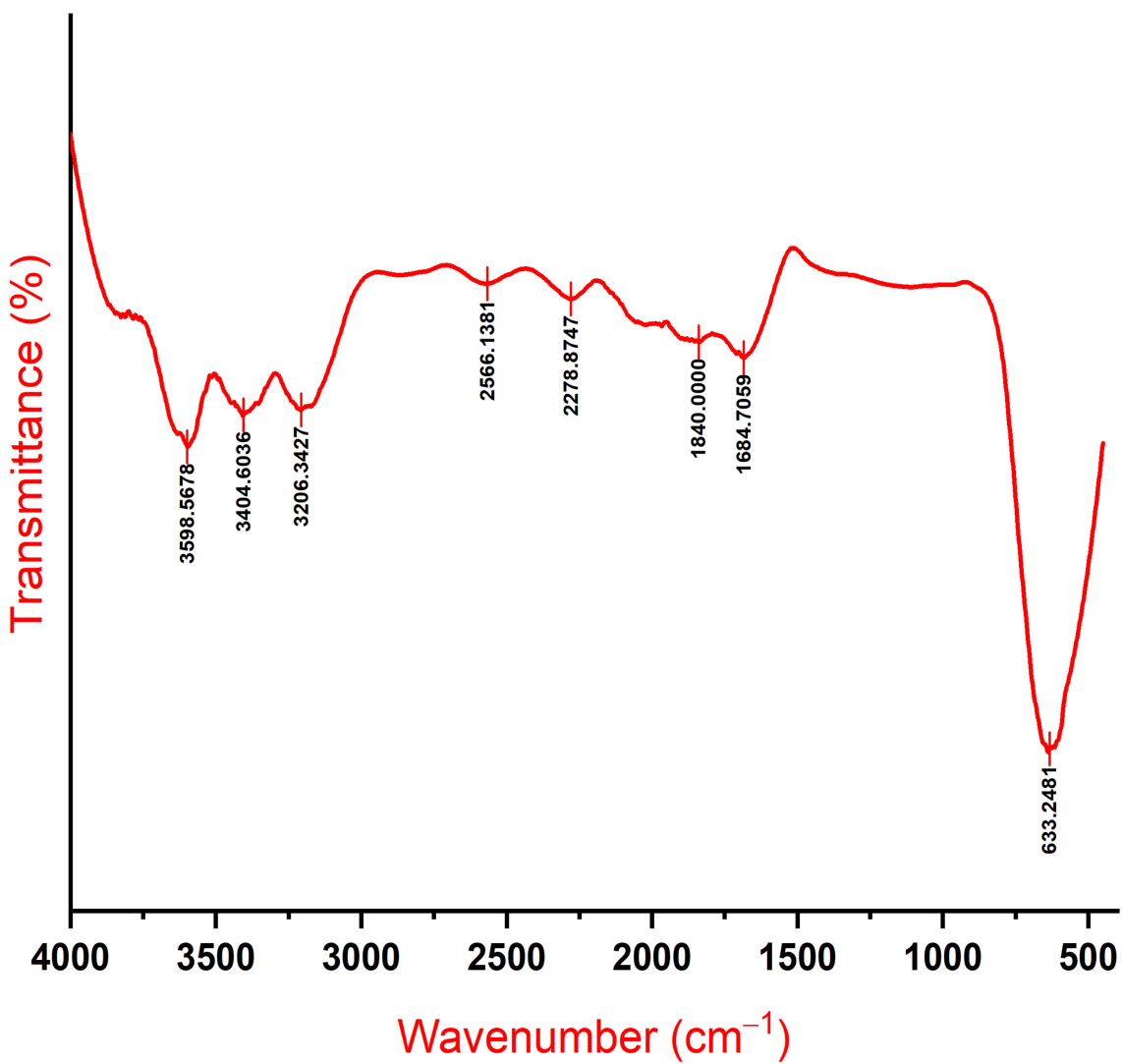


Figure 5

FT-IR spectrograms of Cr_2O_3 synthesis from *Ficus carica* fruit extract

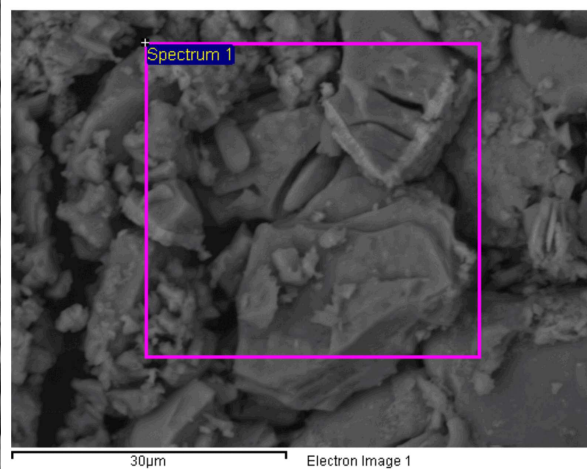
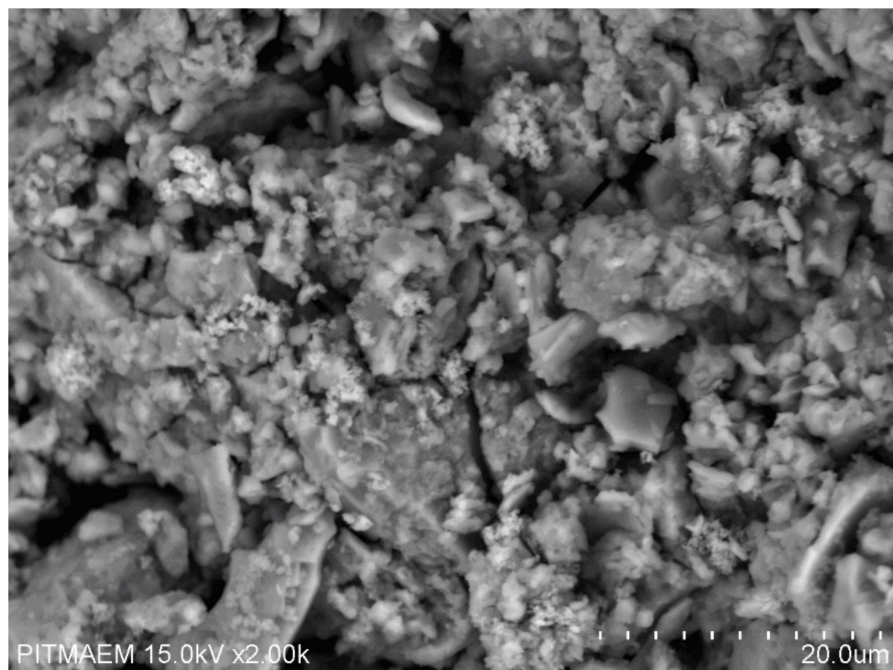


Figure 6

SEM micrograph of Cr_2O_3 nanoparticles synthesized using *Ficus carica* fruit extract at 20 μm scale and 30 μm scale

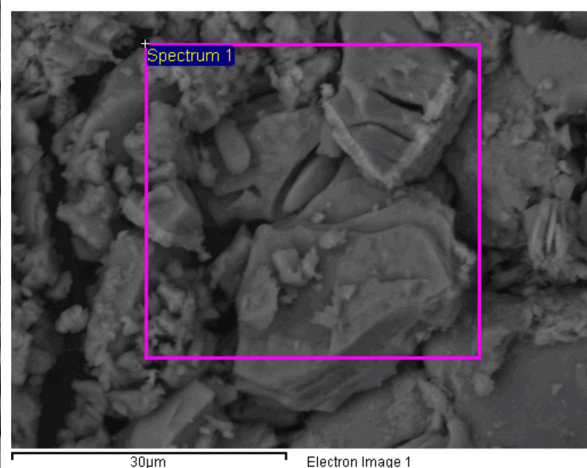
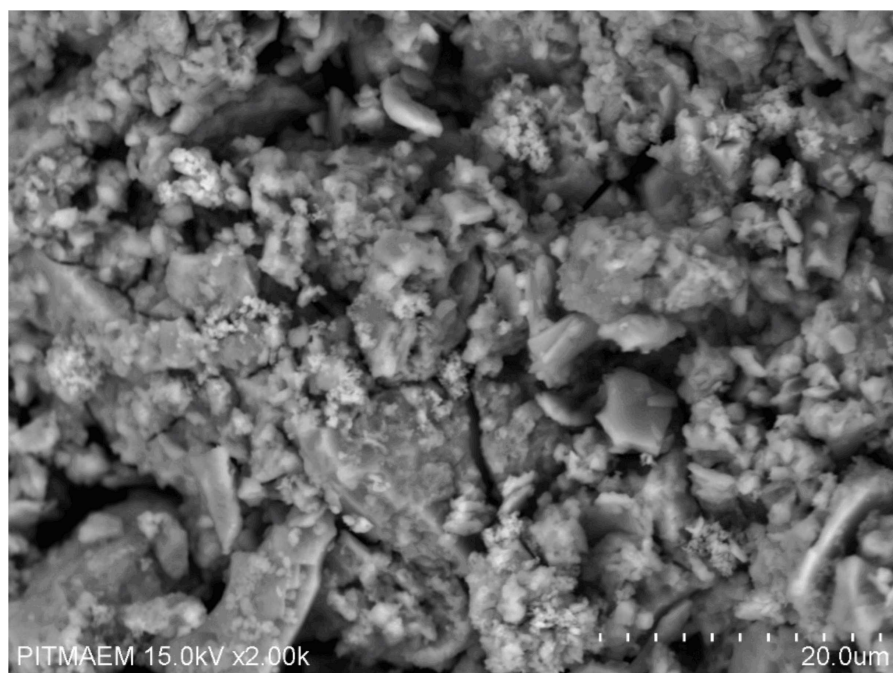


Figure 6

SEM micrograph of Cr_2O_3 nanoparticles synthesized using *Ficus carica* fruit extract at 20 μm scale and 30 μm scale

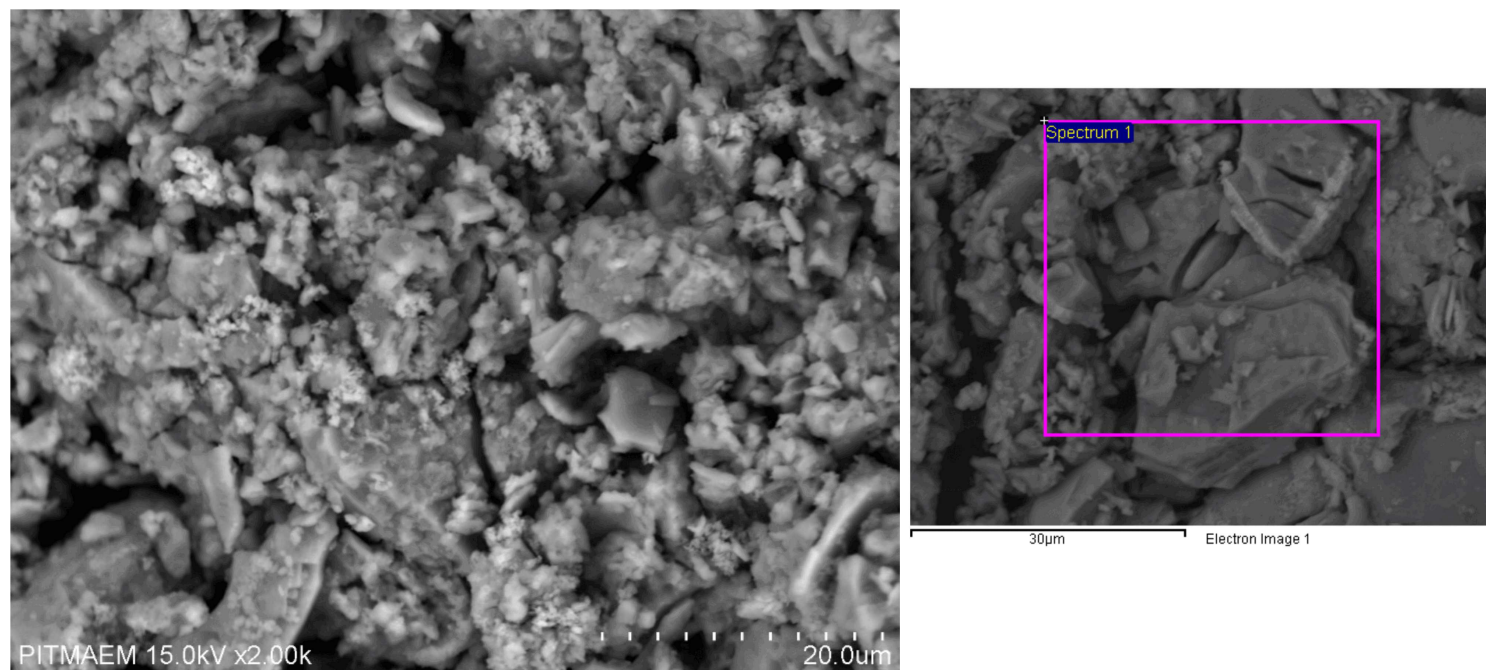


Figure 6

SEM micrograph of Cr_2O_3 nanoparticles synthesized using *Ficus carica* fruit extract at 20 μm scale and 30 μm scale

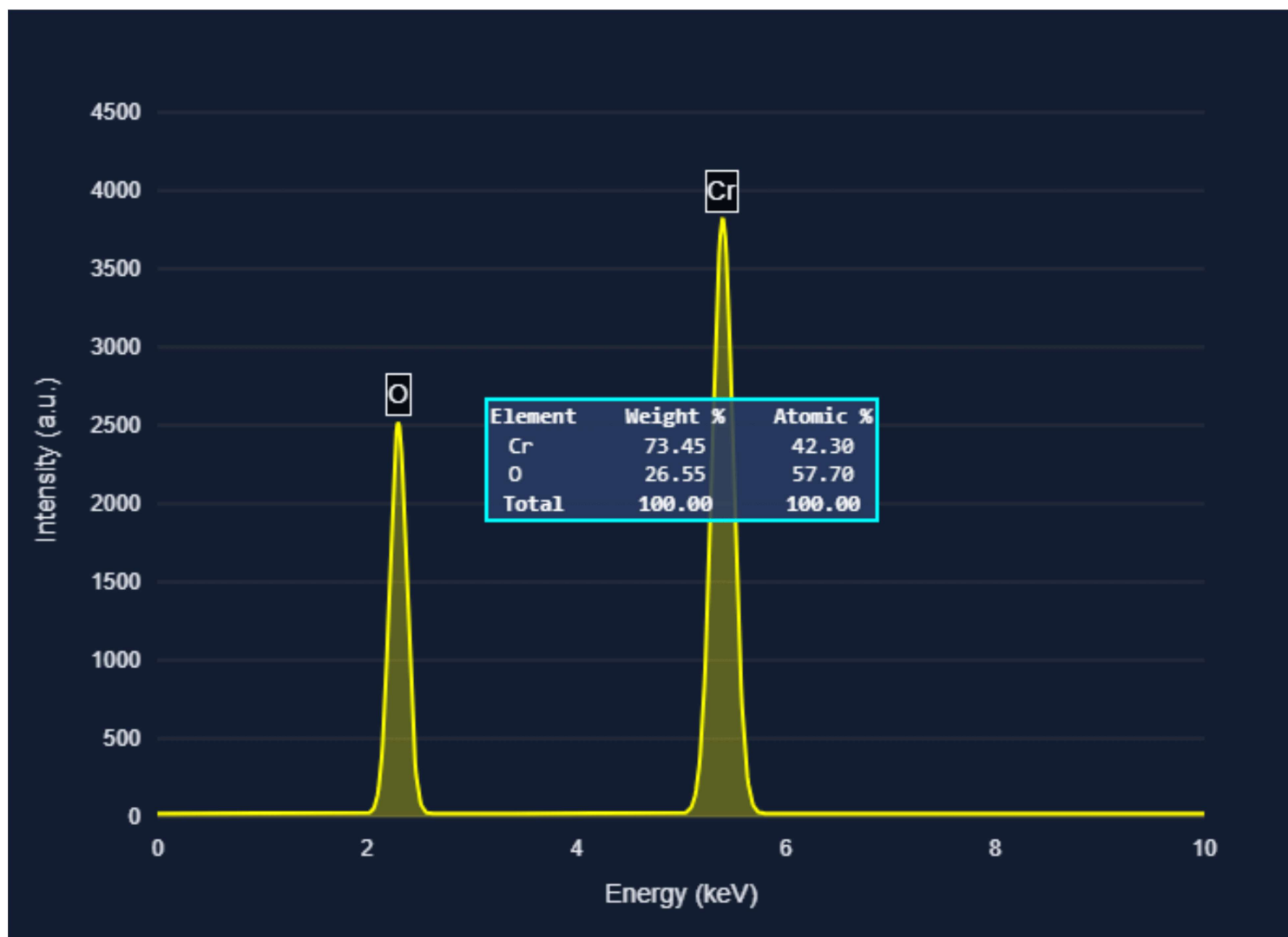


Figure 7

EDX of Cr_2O_3 nanoparticles of *Ficus Carica* fruit

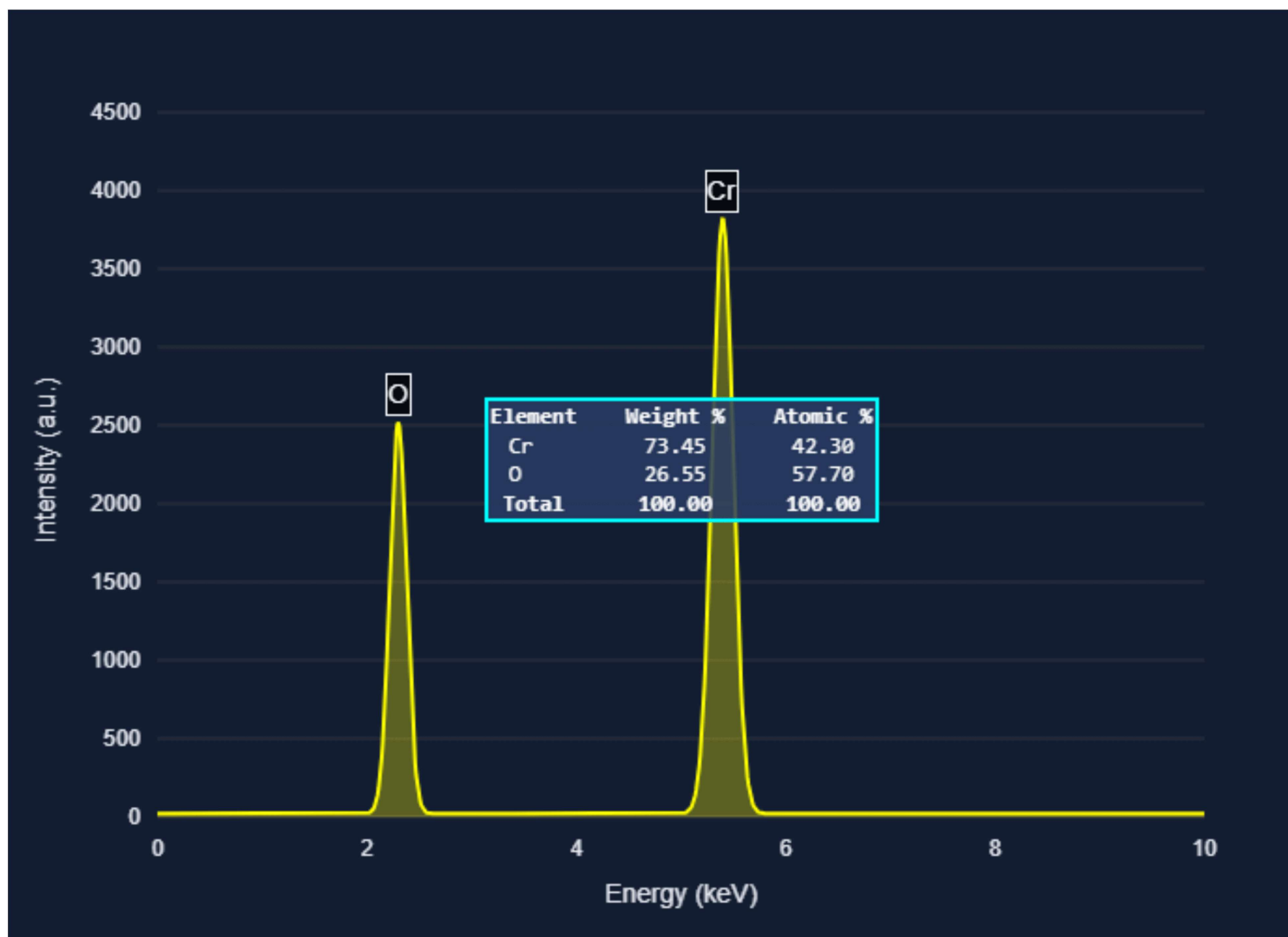


Figure 7

EDX of Cr_2O_3 nanoparticles of *Ficus Carica* fruit

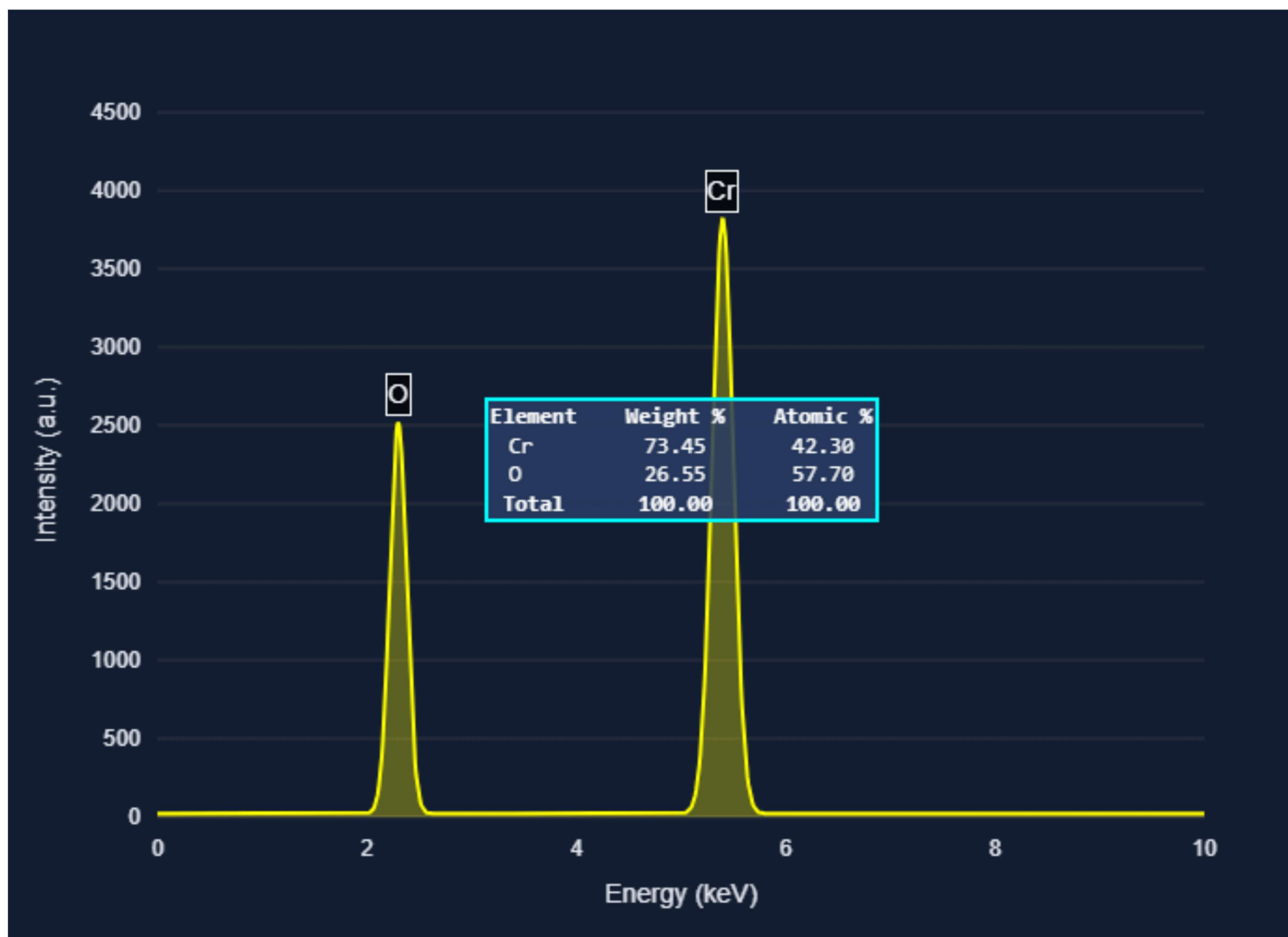


Figure 7

EDX of Cr_2O_3 nanoparticles of *Ficus Carica* fruit

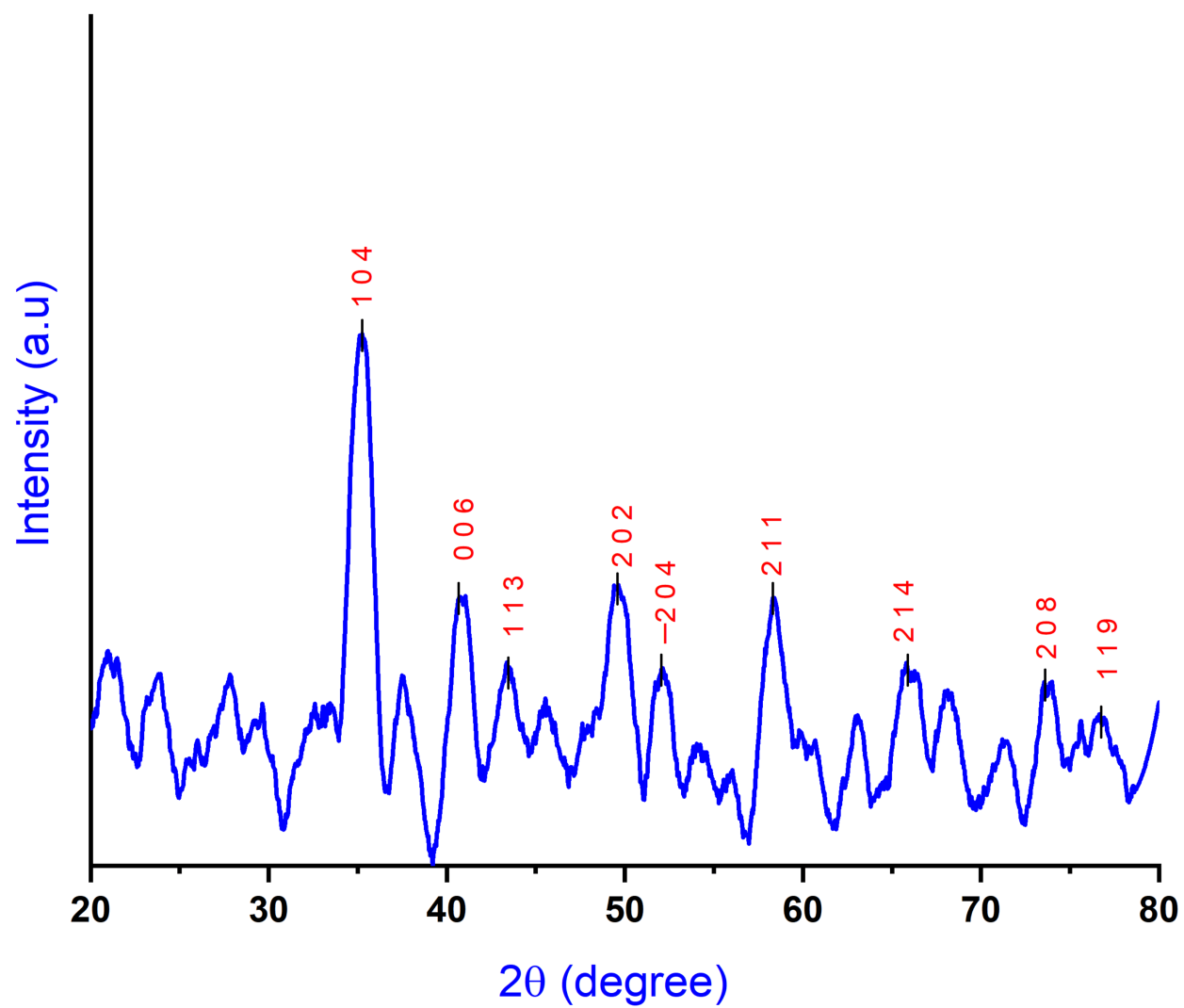


Figure 8

XRD representation of Cr_2O_3 nanoparticles through Fruit extract of *Ficus carica*]

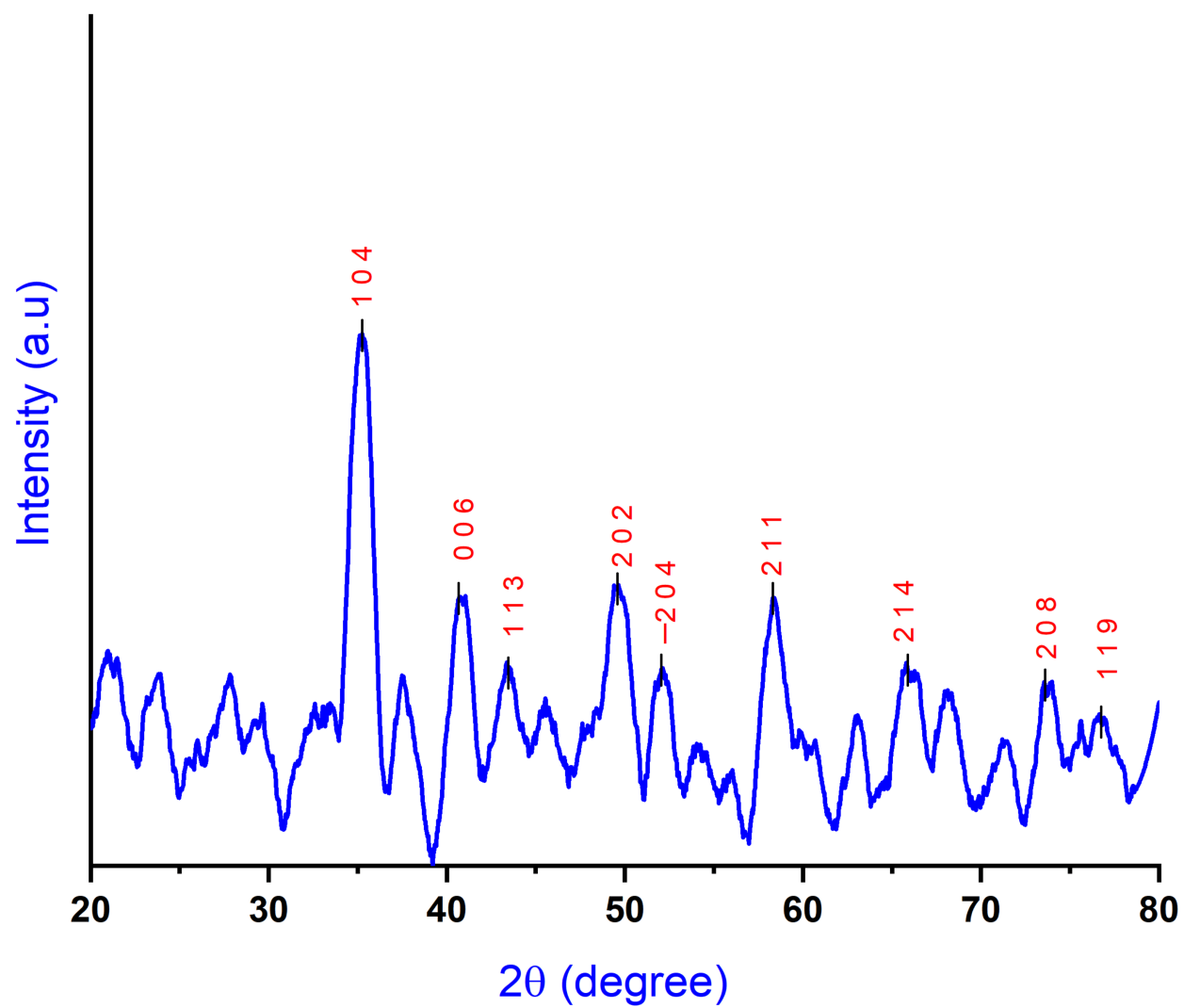


Figure 8

XRD representation of Cr_2O_3 nanoparticles through Fruit extract of *Ficus carica*]

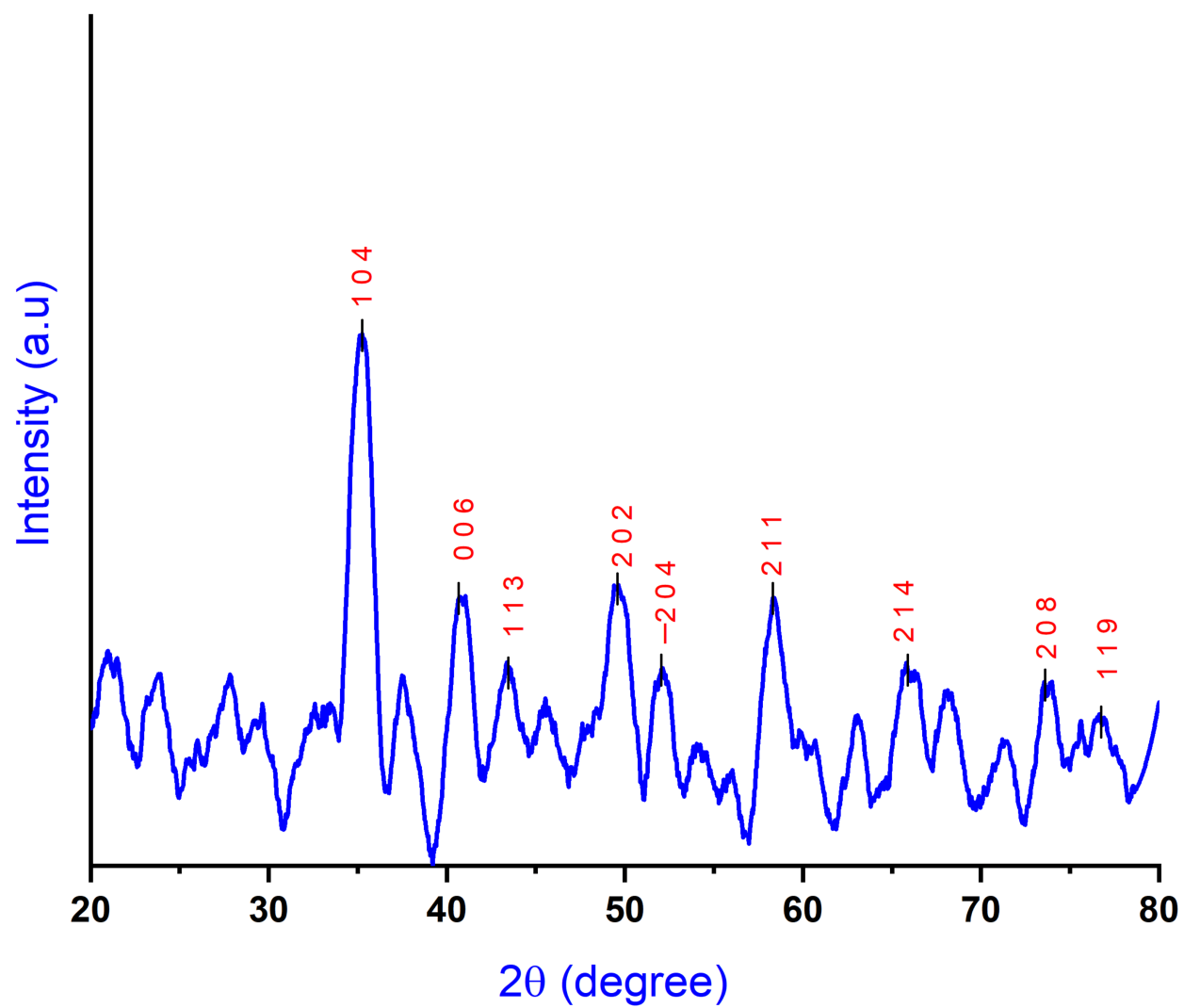


Figure 8

XRD representation of Cr_2O_3 nanoparticles through Fruit extract of *Ficus carica*]

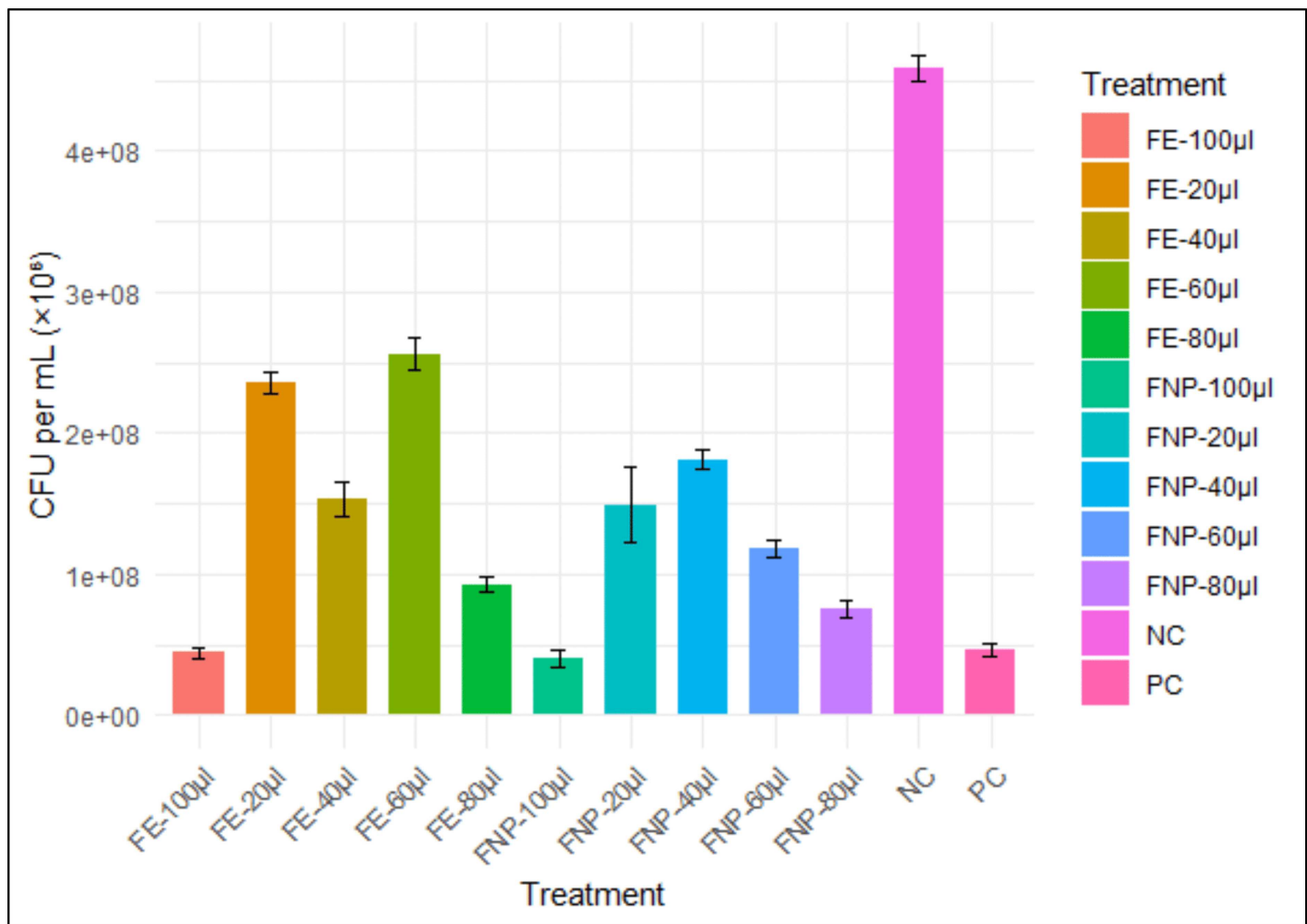


Figure 9

Effects of Cr₂O₃ nanoparticles indicating ZOI in *Escherichia coli* culture

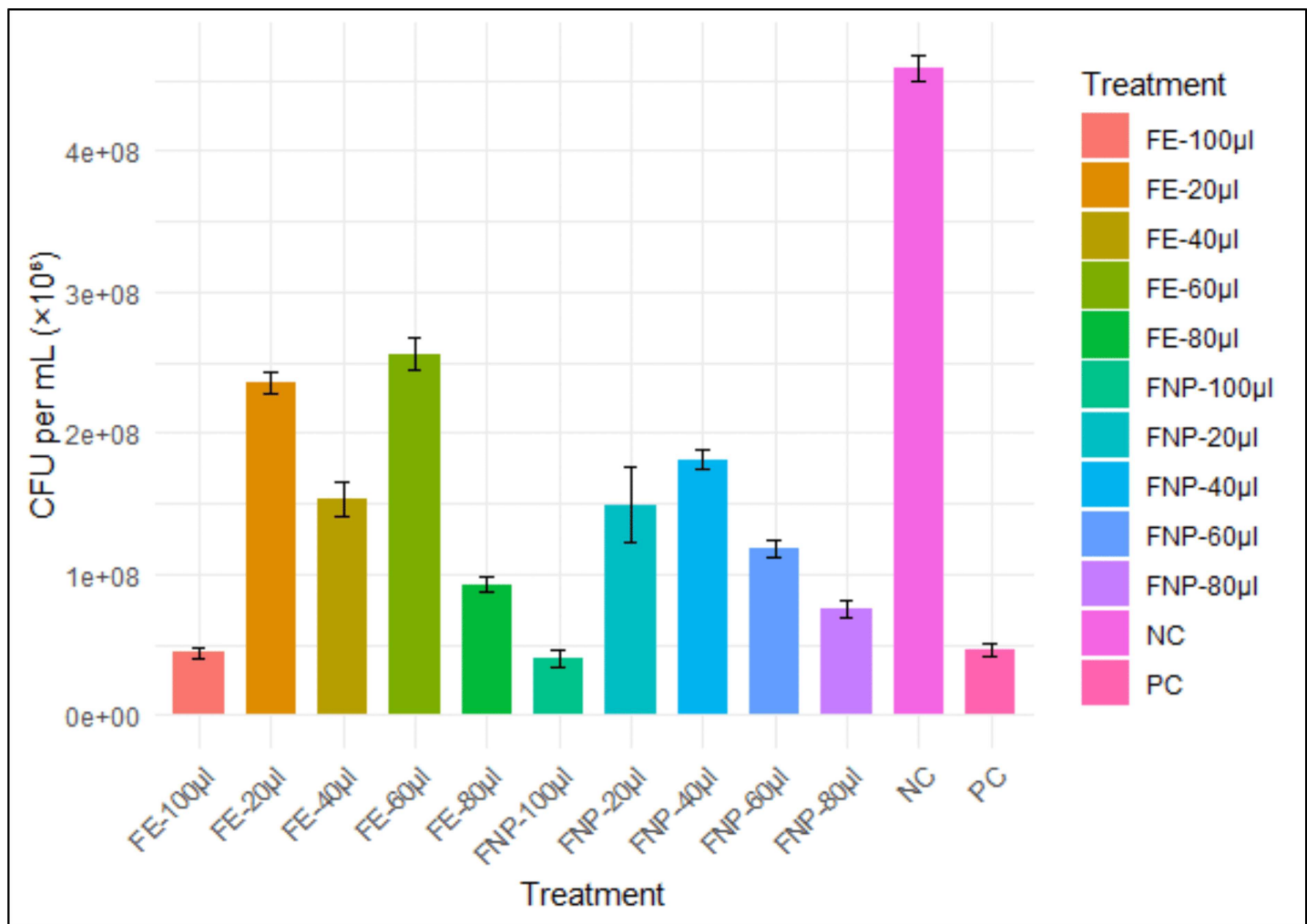


Figure 9

Effects of Cr_2O_3 nanoparticles indicating ZOI in *Escherichia coli* culture

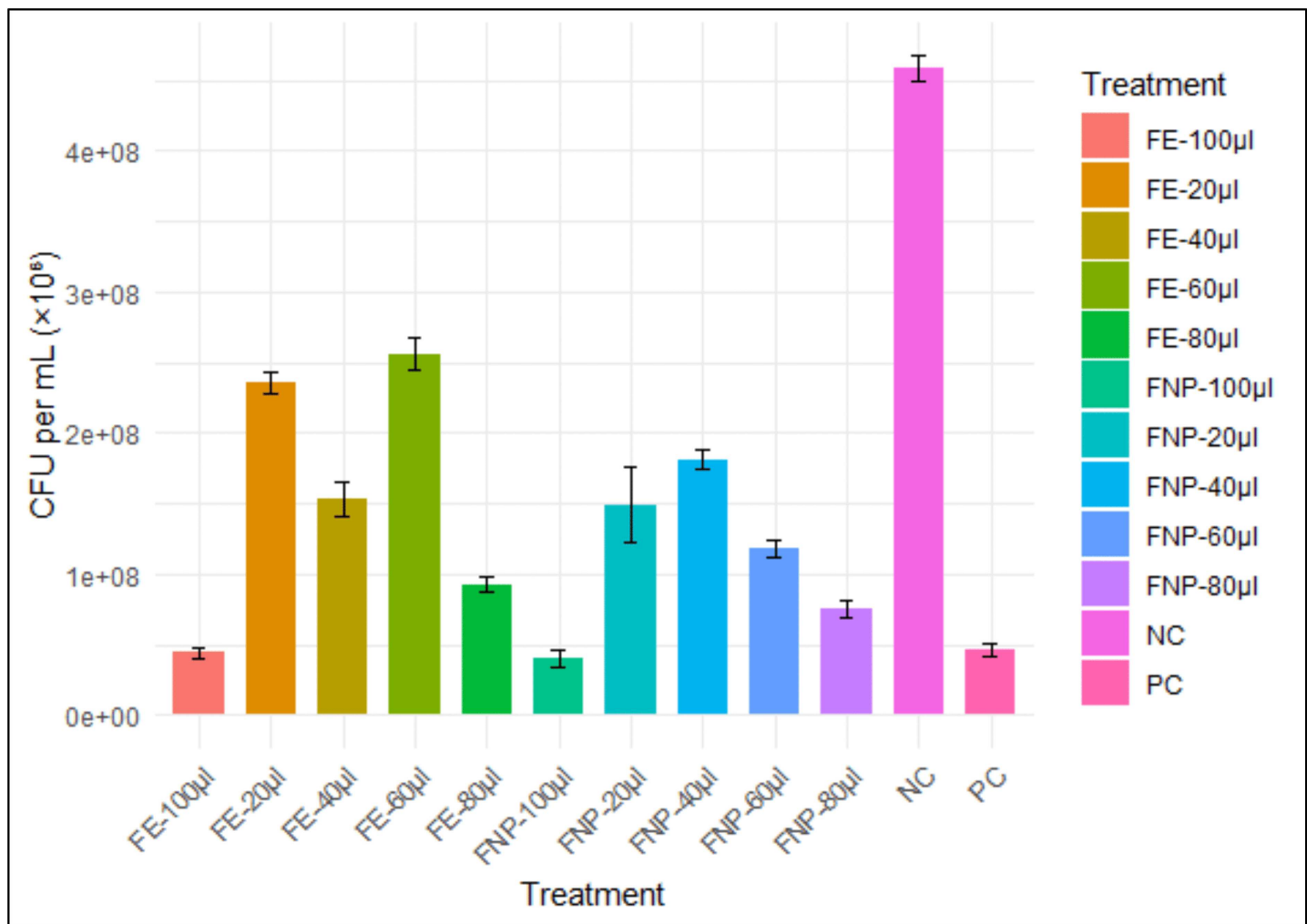


Figure 9

Effects of Cr_2O_3 nanoparticles indicating ZOI in *Escherichia coli* culture

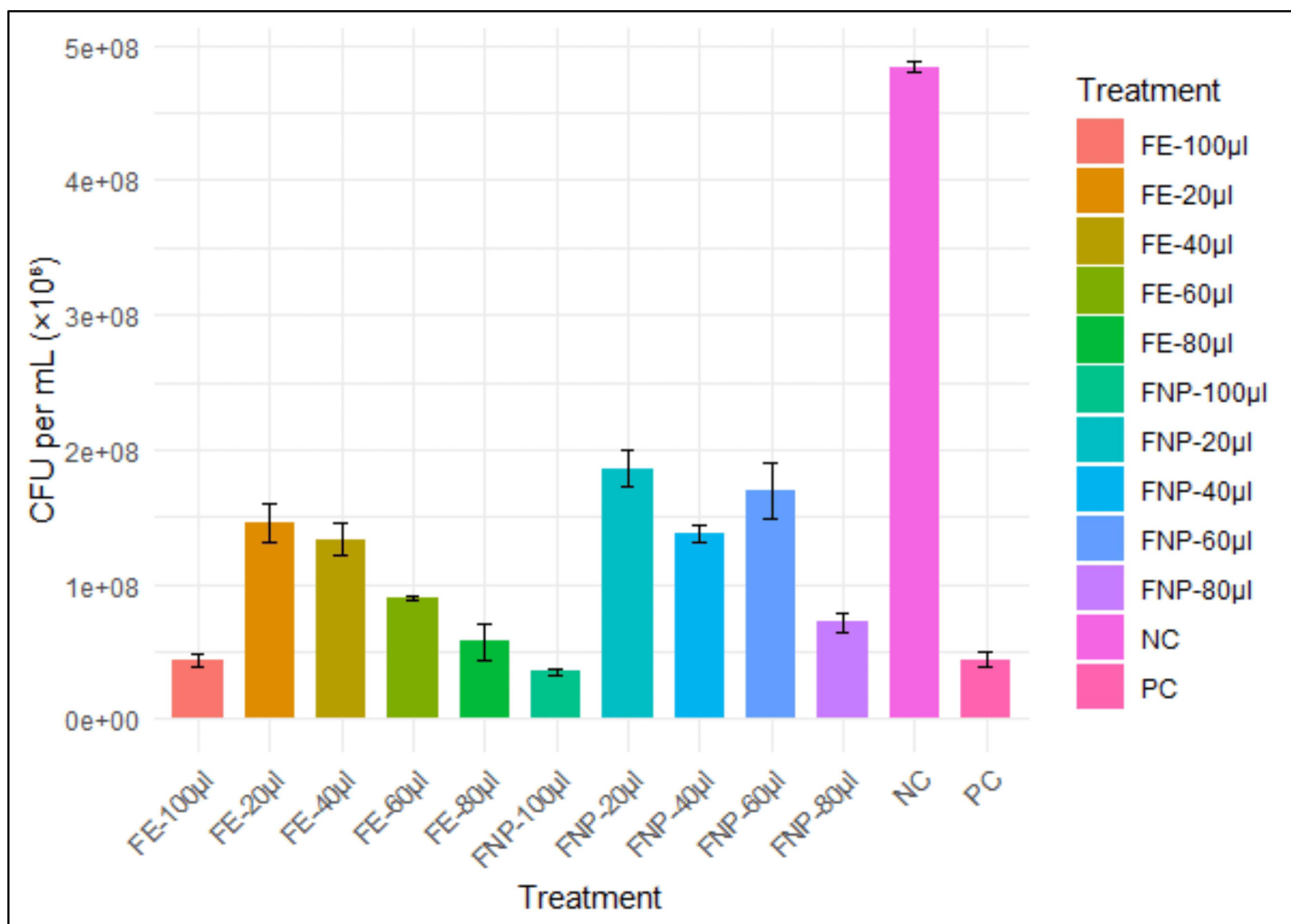


Figure 10

Effects of Cr_2O_3 nanoparticles indicating ZOI in *Bacillus subtilis* culture

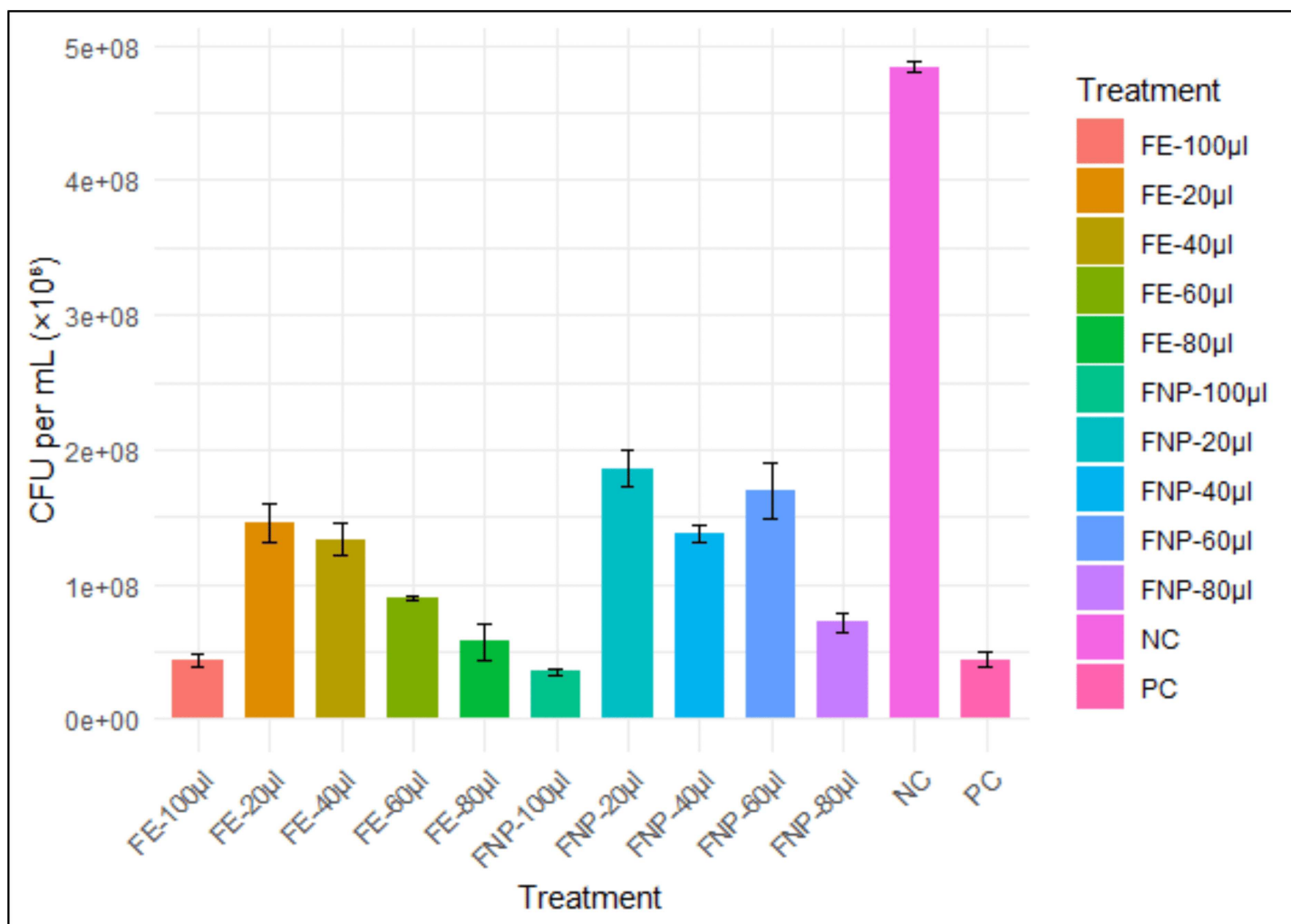


Figure 10

Effects of Cr_2O_3 nanoparticles indicating ZOI in *Bacillus subtilis* culture

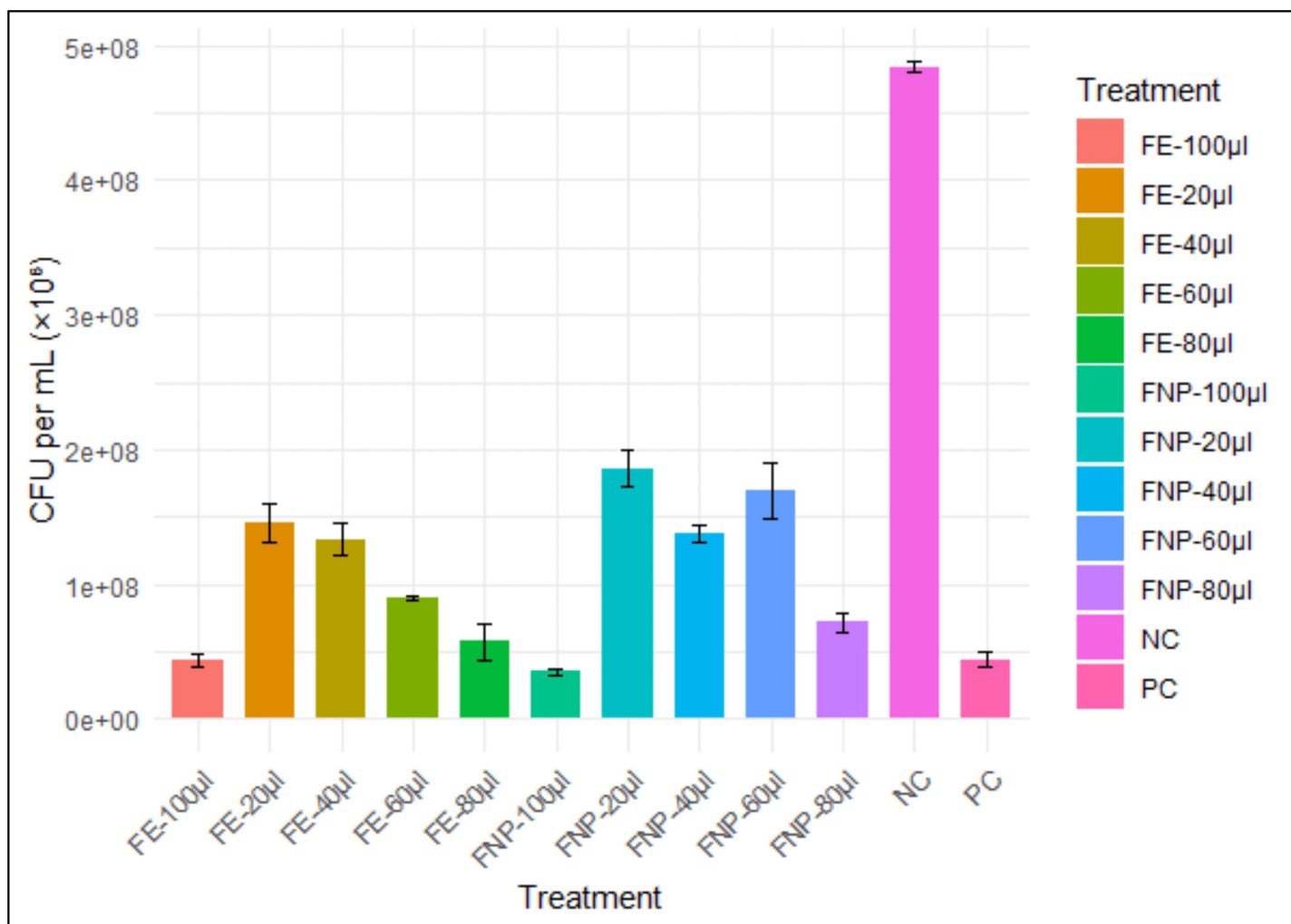


Figure 10

Effects of Cr_2O_3 nanoparticles indicating ZOI in *Bacillus subtilis* culture

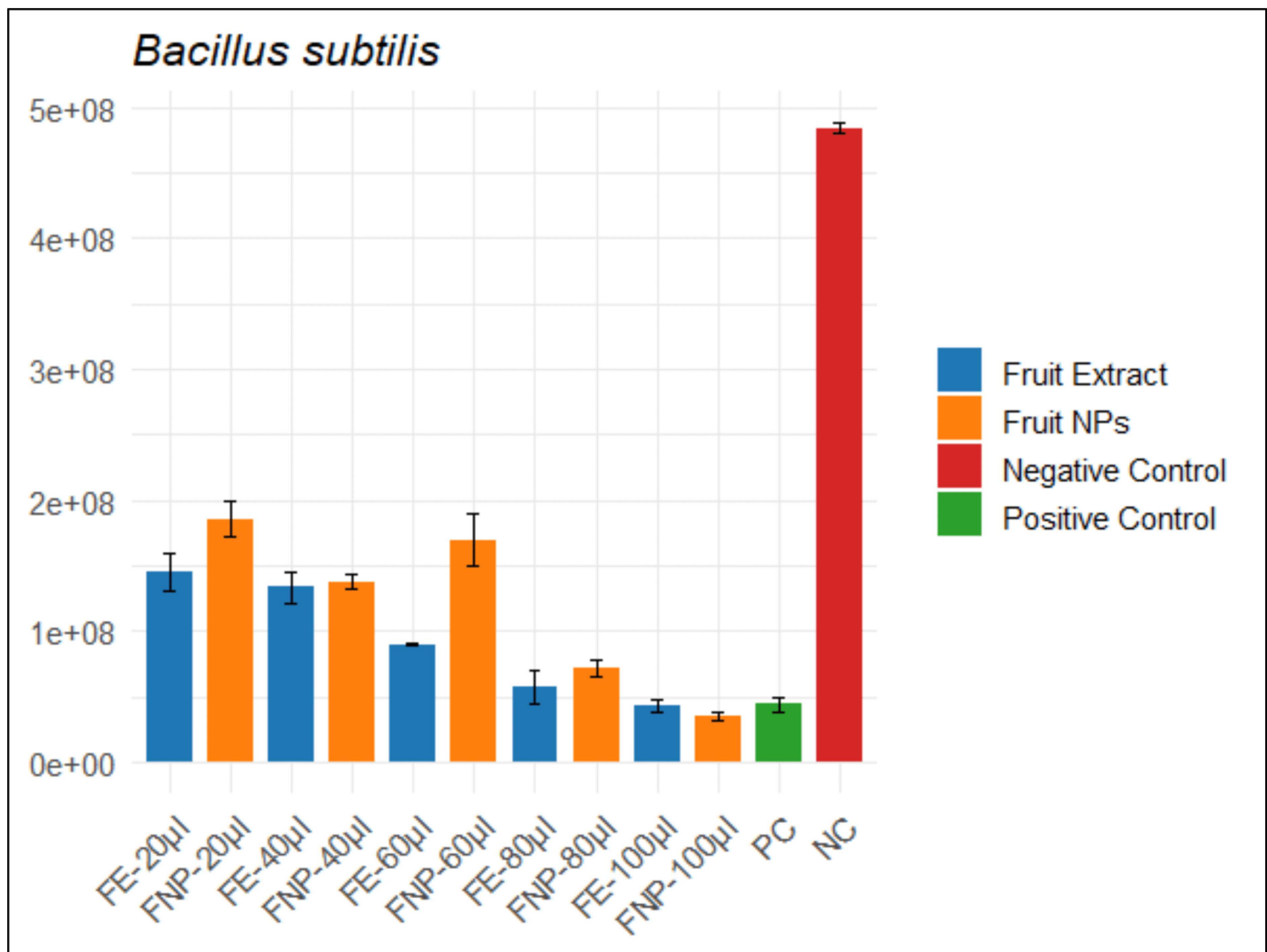


Figure 11

Effects of Cr_2O_3 nanoparticles indicating CFUs in *Escherichia coli* culture

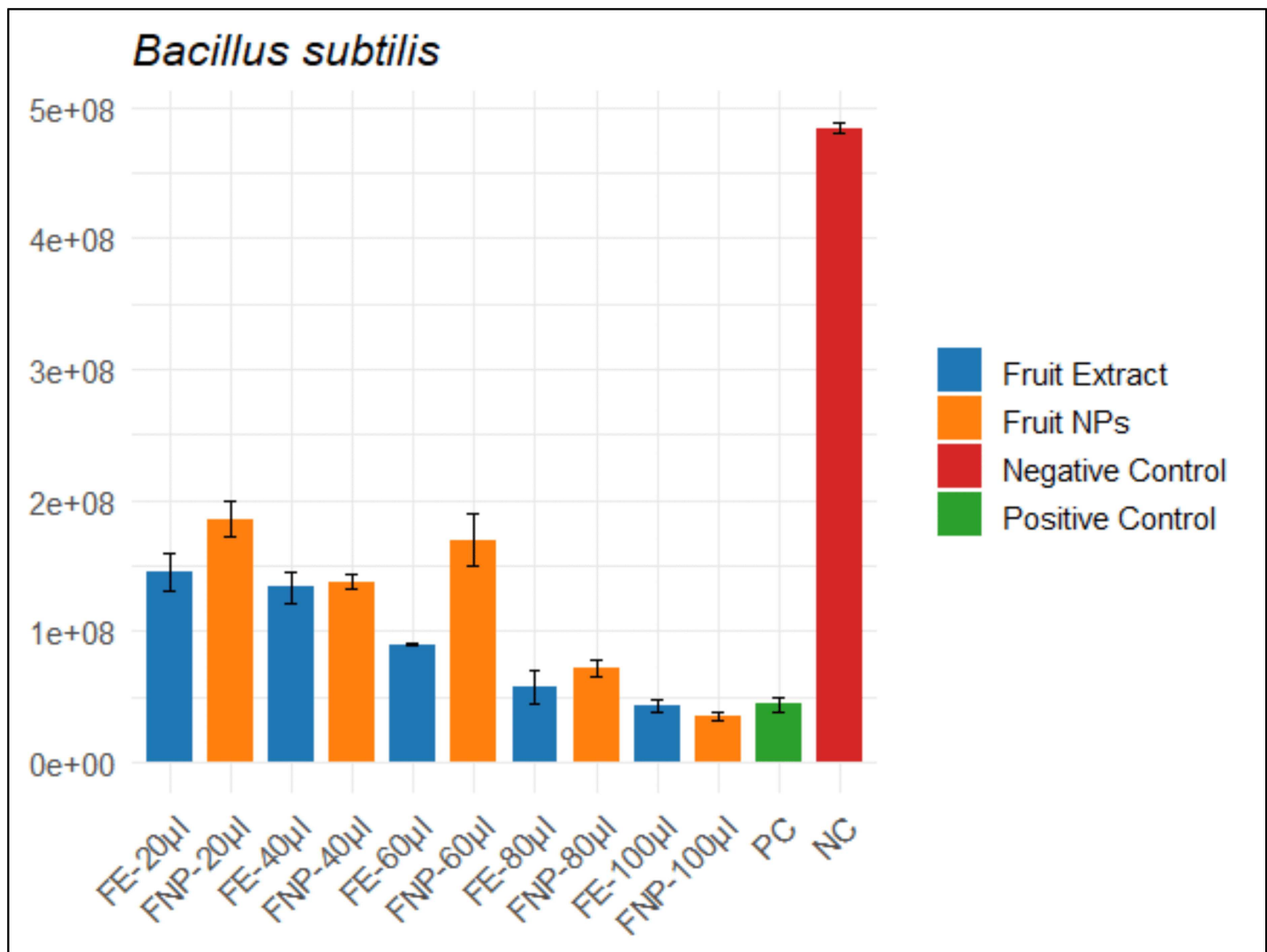


Figure 11

Effects of Cr_2O_3 nanoparticles indicating CFUs in *Escherichia coli* culture

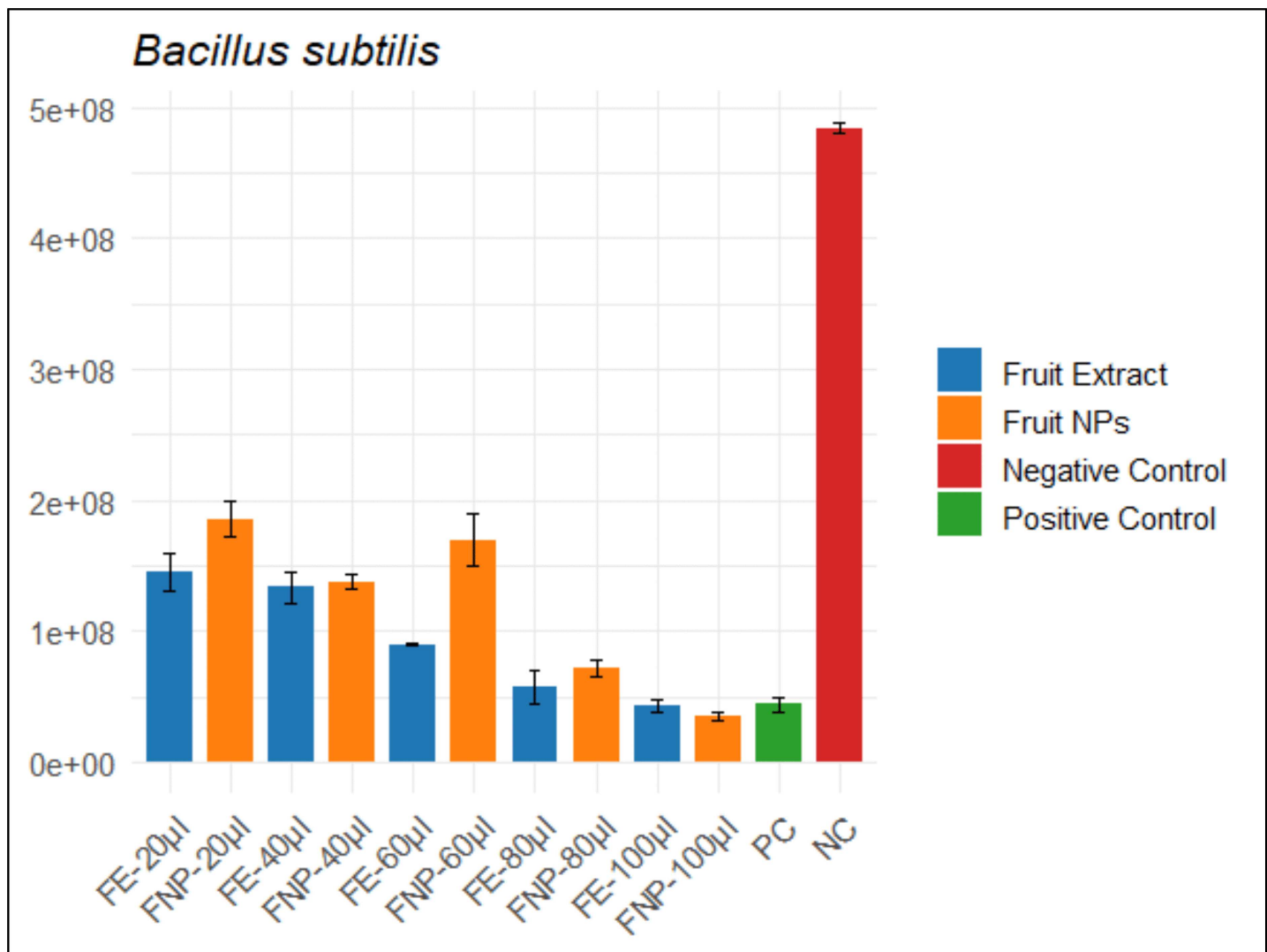


Figure 11

Effects of Cr_2O_3 nanoparticles indicating CFUs in *Escherichia coli* culture

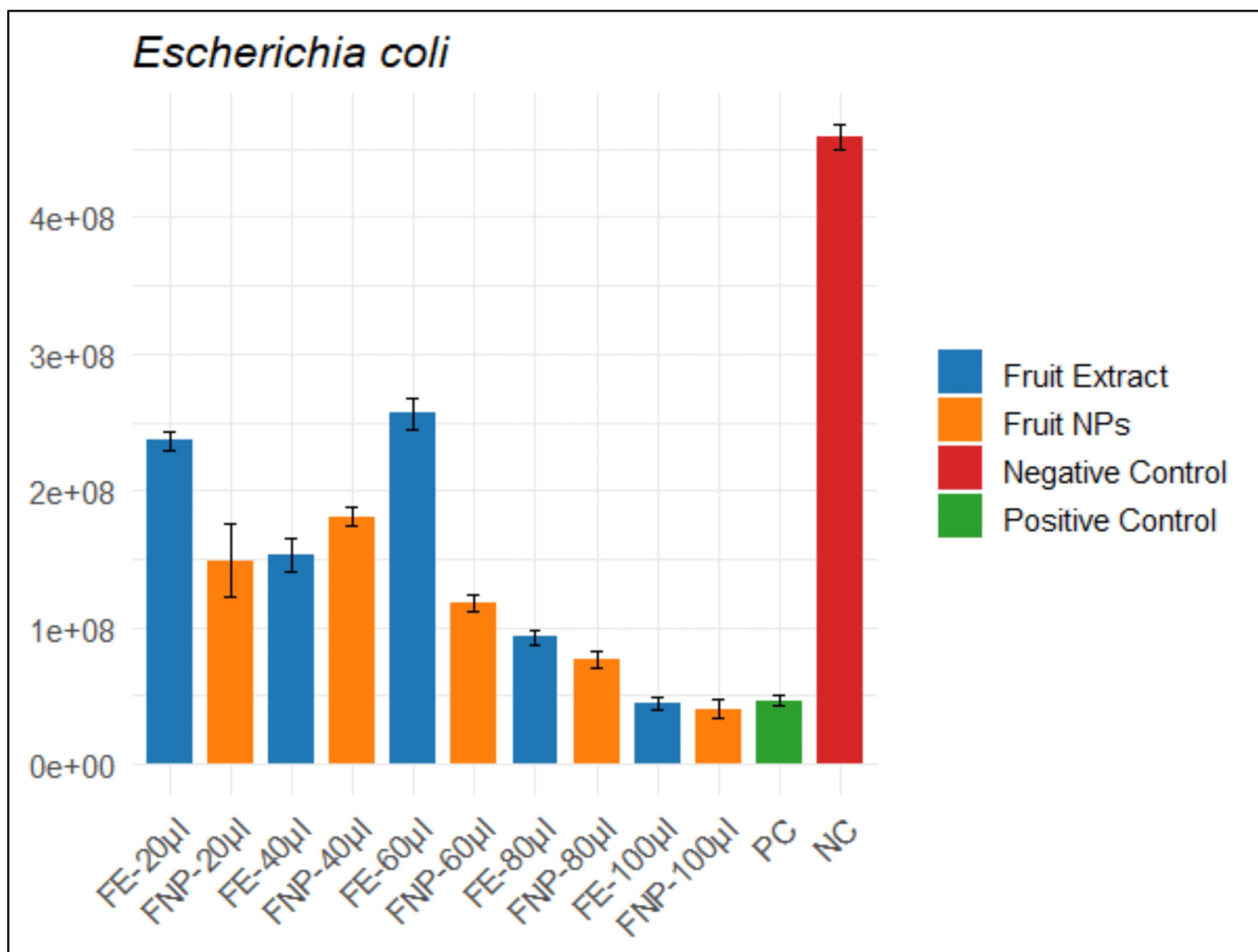


Figure 12

Effects of Cr_2O_3 nanoparticles indicating CFUs in *Bacillus subtilis* culture

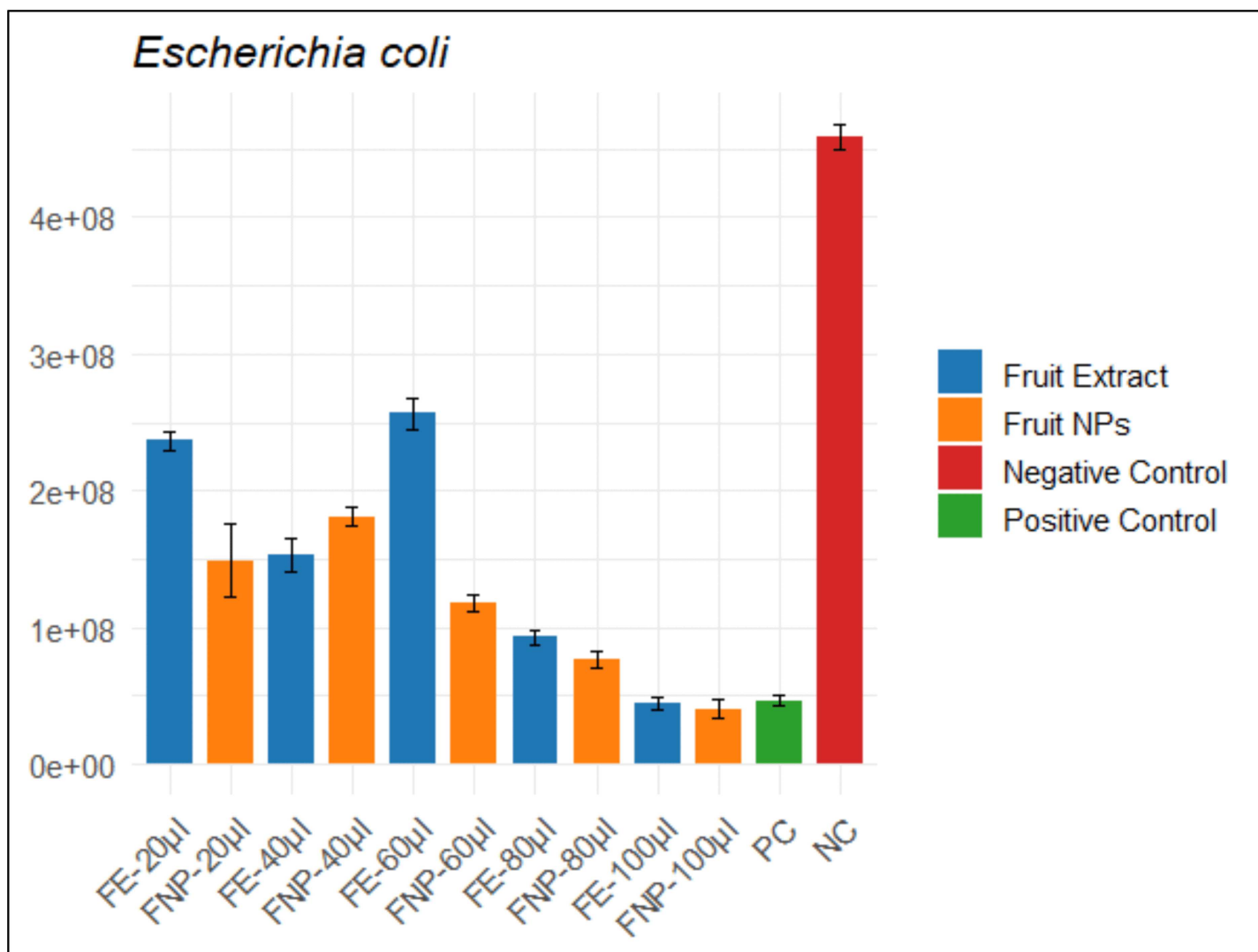


Figure 12

Effects of Cr_2O_3 nanoparticles indicating CFUs in *Bacillus subtilis* culture

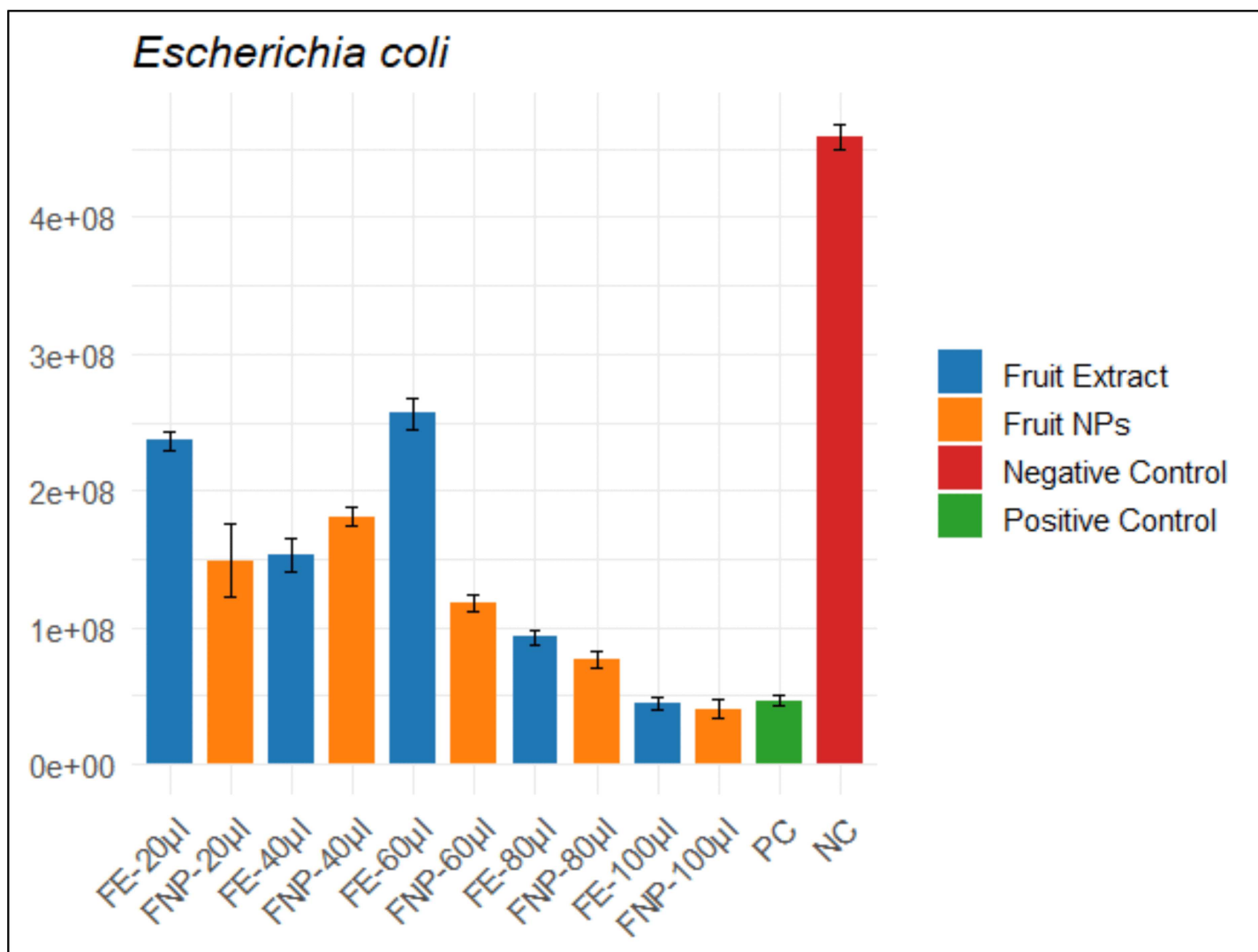


Figure 12

Effects of Cr_2O_3 nanoparticles indicating CFUs in *Bacillus subtilis* culture

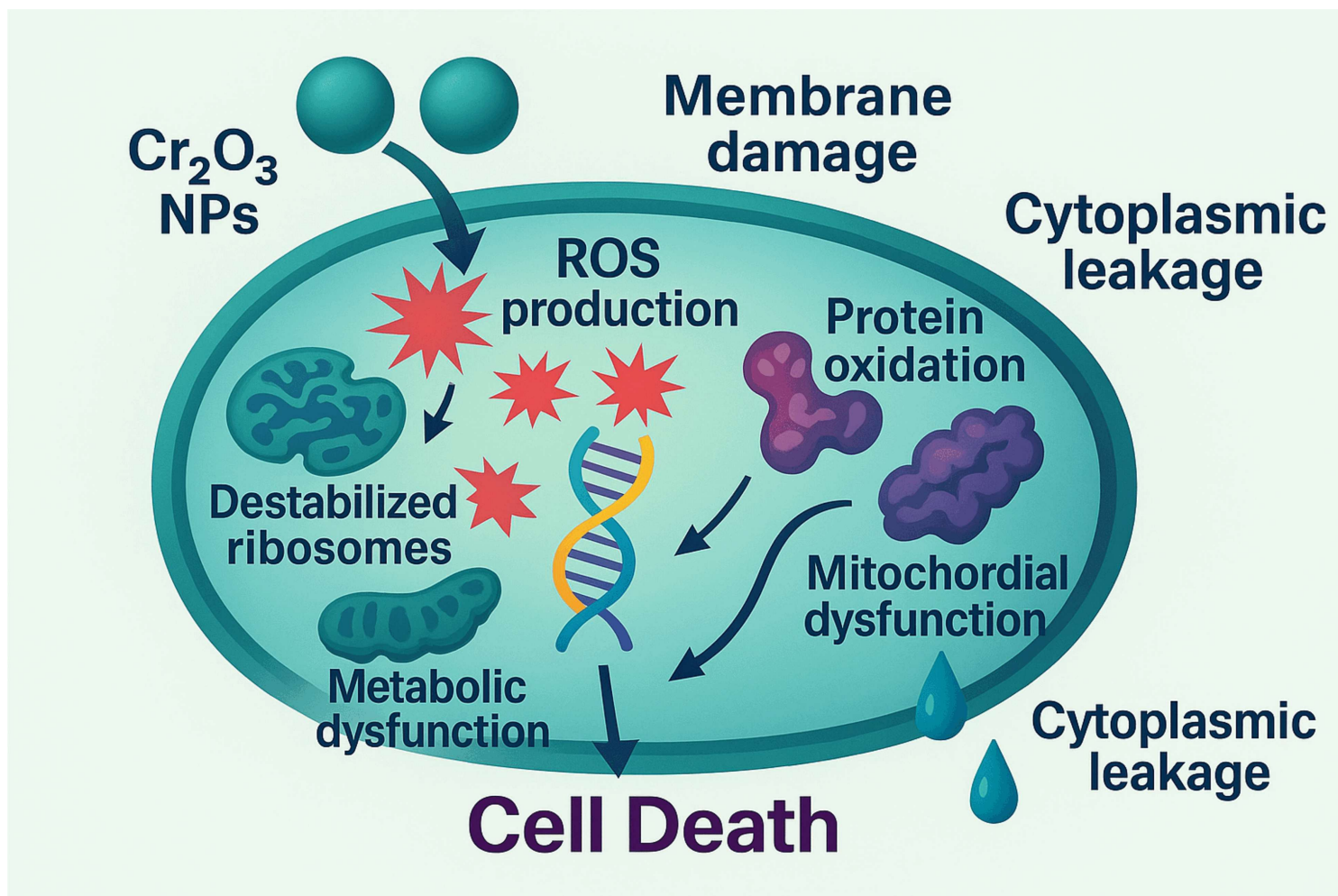


Figure 13

Mechanisms of Action of Nanoparticles Against Bacterial Pathogens

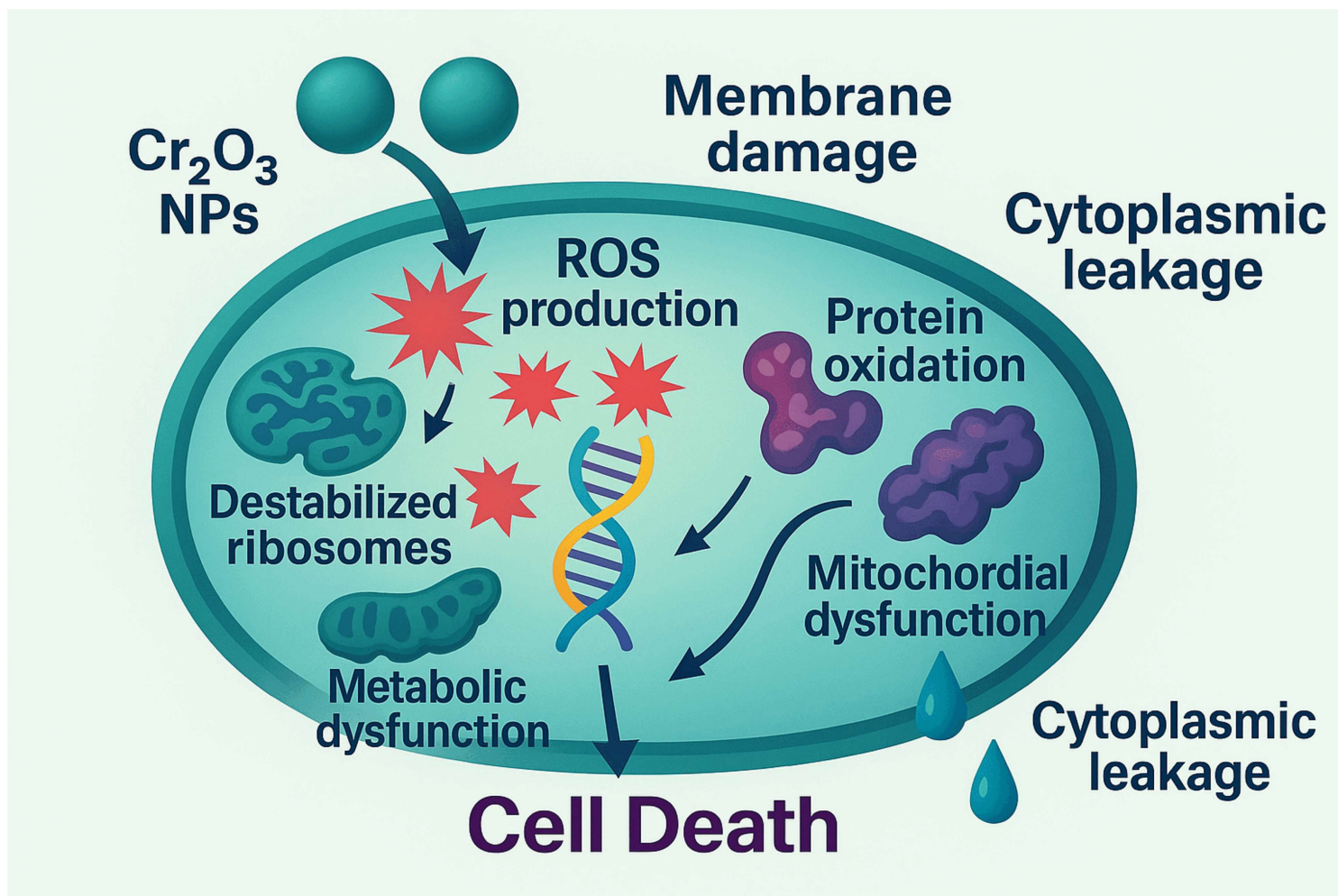


Figure 13

Mechanisms of Action of Nanoparticles Against Bacterial Pathogens

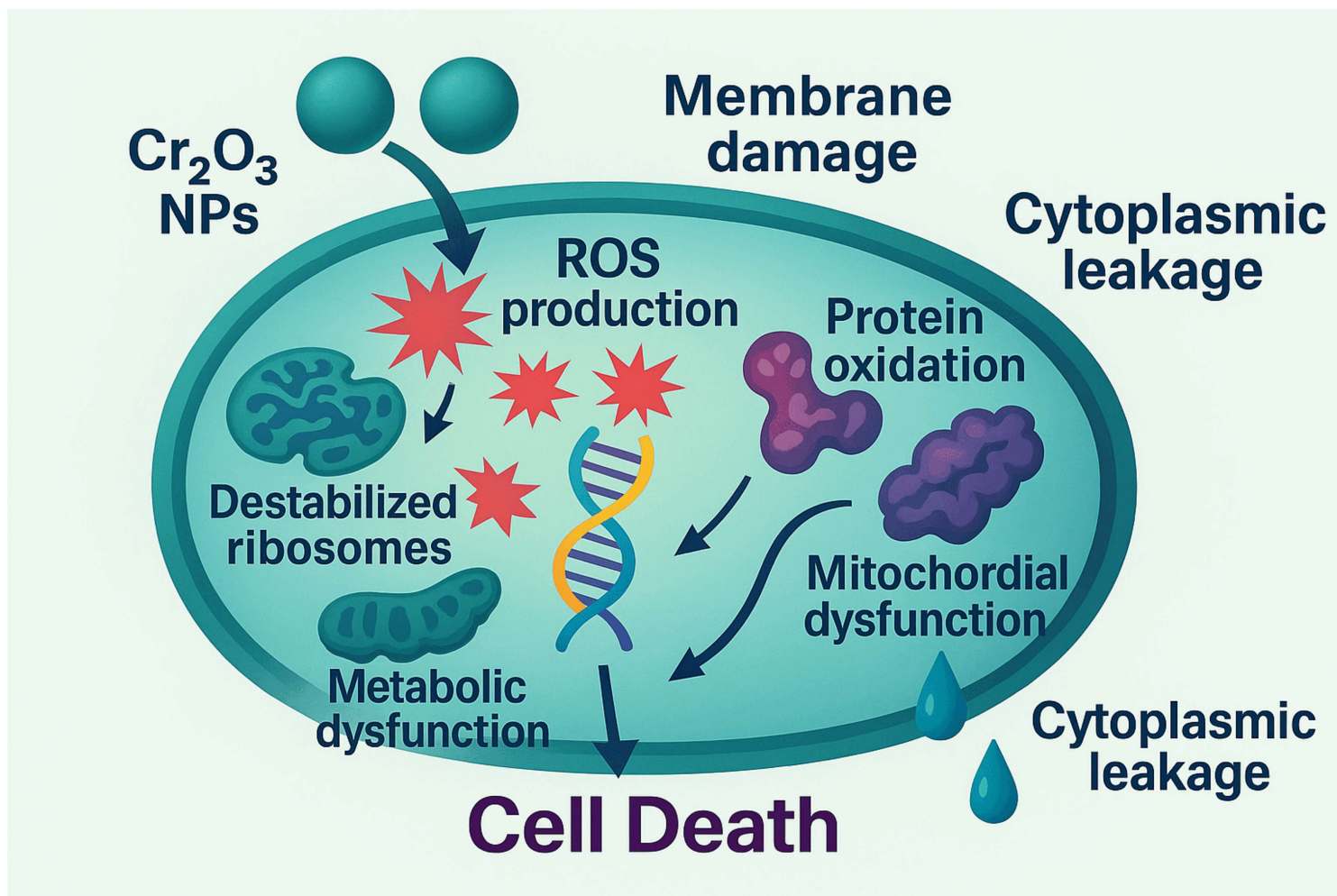


Figure 13

Mechanisms of Action of Nanoparticles Against Bacterial Pathogens

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [tablefile.docx](#)
- [tablefile.docx](#)
- [tablefile.docx](#)