

5-29-2026

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Ulwali, Ruqayah A. and Abass, Nada K. (2026) "Preparation and Characterization of Fe₂O₃ and Fe₂O₃@Ag/AgCl Core-Shell NPs Using Mint Leaf Extract, and Study of Their Cytotoxicity and Inhibition of Breast Cancer Cells," *Baghdad Science Journal*: Vol. 23: Iss. 5, Article 30.
DOI: <https://doi.org/10.21123/2411-7986.5314>

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RESEARCH ARTICLE

Preparation and Characterization of Fe₂O₃ and Fe₂O₃@Ag/AgCl Core-Shell NPs Using Mint Leaf Extract, and Study of Their Cytotoxicity and Inhibition of Breast Cancer Cells

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ABSTRACT

Iron oxide nanoparticles (Fe₂O₃) and iron oxide core–silver/silver chloride shell nanoparticles (Fe₂O₃@Ag/AgCl) were green-synthesized using mint leaf extract. X-ray diffraction (XRD) results showed that Fe₂O₃ formed in two phases, γ -Fe₂O₃ and α -Fe₂O₃, while Fe₂O₃@Ag/AgCl formed in one phase, α -Fe₂O₃, with crystallite sizes increasing from 1.89 nm for Fe₂O₃ to 22.42 nm for Fe₂O₃@Ag/AgCl. Transmission electron microscopy (TEM) revealed that Fe₂O₃ had a heterogeneous structure with nanoclusters, while Fe₂O₃@Ag/AgCl exhibited a uniform Ag/AgCl coating around the iron oxide core, indicating successful coating. FTIR analysis identified peaks corresponding to Fe–O bonds at 559.56 cm⁻¹ and 472.05 cm⁻¹ with the presence of functional groups due to the components of the plant extract. Atomic force microscopy (AFM) showed that Fe₂O₃@Ag/AgCl had a smoother surface and larger crystal size (58 nm) compared to Fe₂O₃ (39 nm), with lower surface roughness of 3 nm compared to 12 nm for Fe₂O₃. UV–Vis analysis showed absorption in UV region with a plasmonic peak in the visible range, with E_g were 3.57 eV and 3.41 eV for Fe₂O₃ and Fe₂O₃@Ag/AgCl, respectively. Cytotoxicity test was performed on normal rat embryo fibroblast (REF) cells and growth inhibition test of MDA breast cancer cells using a concentration (50 μ g / ml) with a series of dilutions)100%, 50%, and 25(%) for two periods)24 and 48 (hours, Fe₂O₃@Ag/AgCl showed greater toxicity to (REF) cells, but within the permissible limits and more effective growth inhibition of breast cancer (MDA) cells compared to Fe₂O₃, especially after 48 hours.

Keywords: Breast cancer, Cytotoxicity, Fe₂O₃ NPS, Fe₂O₃@Ag/AgCl Core-Shell NPs, Green method

Introduction

Nanoparticles are materials that have shown promising potential in many medical and industrial applications. Their unique properties, due to their small size, allow them to interact in various ways with cells and tissues.^{1,2} Among these materials, iron oxide (Fe₂O₃) stands out as a nanoparticle with unique magnetic properties, making it ideal for use in therapeutic and diagnostic applications, such as therapeutic targeting and drug delivery.^{3–5} Recent studies have demonstrated that Fe₂O₃-based nanostructures

exhibit notable anticancer activity against various tumor cell lines, including breast cancer models such as MDA-MB-231. Their anticancer effects are primarily mediated through the generation of reactive oxygen species (ROS), disruption of mitochondrial membrane potential, and induction of programmed cell death mechanisms such as apoptosis and ferroptosis.^{6–8} However, to improve the properties of Fe₂O₃ and enhance their effectiveness, nanoparticles are coated with a layer of other materials, known as the core – shell method. In this method, nanoparticles are made of one material (such as iron oxide) and coated with a thin layer of another material (such as silver or silver

Received 3 July 2025; revised 29 October 2025; accepted 30 October 2025.
Available online 29 May 2026

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<https://doi.org/10.21123/2411-7986.5314>

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chloride) to enhance their properties.⁹ Silver has antibacterial and antiviral properties, it can also interact with cancer cells in multiple ways, silver ions penetrate cancer cells and cause reactions that damage their DNA, stimulating their programmed death.^{10,11} While silver chloride is characterized by its ability to respond to light, which increases the effectiveness of these particles in medical applications, such as phototherapy against cancer cells.¹² The green method is one of the modern methods for preparing nanoparticles that is characterized by being environmentally friendly and uses natural materials to prepare these particles, mint leaf extract was chosen for this study because it contains bioactive compounds such as flavonoids, polyphenols, and terpenoids, which act as reducing and stabilizing agents during nanoparticle synthesis. These plant compounds help reduce toxic effects on the environment and improve the biological interaction of nanoparticles with living organisms.^{13–15} The aim of this study is to evaluate the cytotoxicity and inhibition efficacy of Fe₂O₃ and Fe₂O₃@Ag/AgCl NPs in breast cancer cells, providing an opportunity to explore their potential in future cancer treatments. The study also aims to improve the stability of nanoparticles and increase the therapeutic efficacy of encapsulated materials.

Materials and methods

Preparation of mint leaf extract

Mint leaf extract) from local markets (was prepared after drying and cutting the leaves into small pieces. 10 grams of the extract were taken, 250 ml of deionized water was added, and the mixture was left in a magnetic stirrer for 1 hour at 60°C, stirring continuously to ensure even heat distribution. The extract was then filtered using gauze and centrifuged for 30 minutes at 4000 rpm. It was then left to cool until ready to use, (The final concentration, based on the mass dissolved in the solution, was 40 g/L.).

Preparation of iron oxide NPs

According to a study Yousaf R et al.¹⁶ Iron oxide nanoparticles were prepared using 0.1 M of iron nitrate Fe(NO₃)₃ · 9H₂O (Daryaganj, Delhi, India, 98%), which was dissolved in 50 ml of deionized water. Then, 30 ml of mint leaf extract was added, the solution was observed to be greenish-black in color and PH=4 the reaction was left for one hour with continuous stirring under a magnetic stirrer. The resulting precipitate was separated using centrifugation for 30 min at 4000 rpm. After that, the precipitate

was washed twice with deionized water and once with ethanol (98%) for 30 min. The precipitate was allowed to dry overnight in air at room temperature. The resulting precipitate was black in color. After that, it was annealed for three hours at 600°C, this degree was determined according to a study of Archana V et al.¹⁷

Preparation of Fe₂O₃ @Ag/AgCl core shell NPs

According to a study Sarani M et al.¹⁸ Fe₂O₃ coated with Ag/AgCl were prepared using 0.1 M of iron nitrate Fe(NO₃)₃ · 9H₂O and dissolved in 50 ml of deionized water. Then, 30 ml of mint leaf extract was added, then silver nitrate (CDH, India, 99.9) was added at concentration 0.01 M drop by drop. The reaction continued with continuous stirring for an hour with PH= 4. After that, it was separated and washed three times, and then it was annealed at 600°C for three hours.

Anticancer activity of Fe₂O₃ and Fe₂O₃ @Ag/AgCl core shell NPs

Viable cells count

Tissue culture flasks containing normal and cancer cells were obtained from the Biotechnology Center at Al-Nahrain University, and the growth medium was carefully removed. The flasks were then rinsed twice with 1 mL of trypsin-versene EDTA (Ethylene Diamine Tetraacetic Acid) solution to eliminate residual medium and non-adherent cells. Subsequently, 1 mL of trypsin-versene was added, and the flasks were incubated for 2–5 minutes to facilitate cell detachment. Following detachment, 4–5 mL of PRMI growth medium supplemented with 10% fetal bovine serum (FBS) was added to neutralize the trypsin and maintain cell viability. The viable cells were then counted using a counting chamber under an inverted microscope (400×). The concentration of viable cells (cells/mL) was calculated using the following formula¹⁹:

$$c = n \times \delta \times 10^4 \quad (1)$$

where c represents the viable cell count per milliliter, n is the number of viable cells counted, and δ is the dilution factor (equal to 10).

Cytotoxicity assay and anticancer activity

Cytotoxicity assays were used to show the effect of Fe₂O₃ and Fe₂O₃@Ag/AgCl NPs on REF cell line culture. 10,000 cells were distributed into each well using 96-well microplate. After 24 h incubation period at 37°C, the cells were examined to see if they

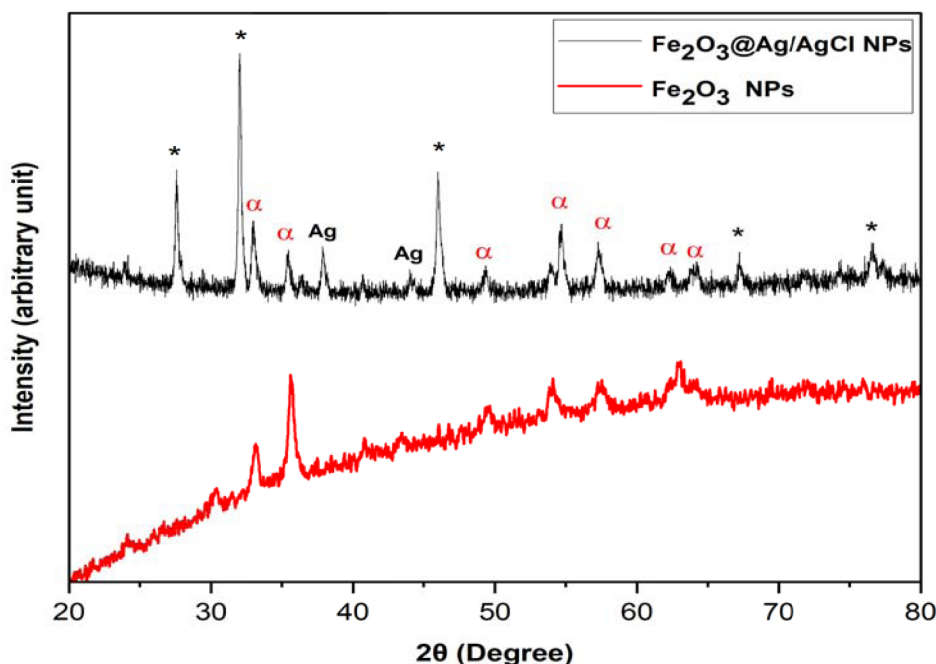


Fig. 1. X-ray diffraction pattern of Fe_2O_3 and $\text{Fe}_2\text{O}_3@Ag/AgCl$ NPs.

had formed a monolayer. Then, the cells were exposed to the series dilute (100%, 50%, and 25%) with autoclaved deionized water of prepared NPs ($50 \mu\text{g} / \text{ml}$), with negative Controls (cells and free media), then incubated at 37°C for 24 h, the same work was repeated with an incubation period of 48 h. After incubation, $70 \mu\text{L}$ of crystal violet (Al-Hann of factory, Jordan) was added to each well for confluence and incubated again for 20 min at 37°C . Then, the microplate was washed with water to be ready for examination. The average of inhibition percentages was calculated using Assay Enzyme-Linked Immunosorbent (ELISA) by a microplate reader at 580 nm for all the groups by Eq. (2)^{19,20}

$$\text{Growth inhibition} = \frac{\text{control} - \text{treatment}}{\text{control}} \times 100\% \quad (2)$$

The same applies to the anticancer activity of breast cancer (MDA) cell line. The process was carried out with three replications, using statistical methods to analyze the significance (ANOVA, and p-values).

Results and discussion

XRD result

X-ray diffraction was used to determine the crystalline structure of the prepared nanoparticles. As

shown in Fig. 1, the pattern of Fe_2O_3 NPs exhibits relatively broad peaks, indicating their nanocrystalline nature and low crystallinity. These peaks were assigned to γ - Fe_2O_3 and α - Fe_2O_3 with a cubic and hexagonal structure correspond to JCPDS card No. 96-101-0370 and (96-900-0140), respectively.²¹ For the coated sample $\text{Fe}_2\text{O}_3@Ag/AgCl$ NPs, the XRD pattern showed sharper and more pronounced peaks. The characteristic peaks marked with (*) indicate the AgCl phase in addition to the appearance of peaks due to Ag phase, which corresponds to JCPDS card No. (01-085-1355) and (98-005-3759) with a cubic structure.²² Since the preparation was carried out using mint leaf extract as a natural source of reducing and stabilizing agents, the extract also contributed to the supply of chloride ions that reacted with silver ions to form an AgCl layer around the Fe_2O_3 nucleus.²³ In addition, the Fe_2O_3 peaks continue to appear, but in the α phase, which is more stable (denoted by α),²⁴ this behavior can be explained by the thermodynamic stability of the α - Fe_2O_3 phase, which is the most stable phase at ambient conditions or during annealing.²⁵ It was also noted that there is an increase in the average crystal size of Fe_2O_3 compared to $\text{Fe}_2\text{O}_3@Ag/AgCl$ NPs from 1.89 nm to 22.42 nm respectively, according to the physical criteria indicated in the Tables 1 and 2 using Eq. (3),²⁶ the observed increase in material quantity after coating is due to the addition of the shell material Ag/AgCl around the Fe_2O_3 core, which increases both the mass and volume of the resulting nanoparticles. The an-

Table 1. The structural parameters of Fe₂O₃ NPs.

Sample	2 θ (Deg.)	FWHM (Deg.)	d _{hkl} Exp.(Å)	C.S (nm)	hkl	Phase
Fe ₂ O ₃	30.379	7.2003	2.9399	1.14	(022)	γ -Fe ₂ O ₃
	33.162	3.1900	2.6993	2.60	104))	α -Fe ₂ O ₃
	35.615	2.7610	2.5188	3.02	(131)	γ -Fe ₂ O ₃
	43.469	6.9850	2.0802	1.22	(040)	γ -Fe ₂ O ₃
	49.629	6.9300	1.8354	1.26	(20-4)	α -Fe ₂ O ₃
	54.095	5.2580	1.6940	1.70	(116)	α -Fe ₂ O ₃
	57.538	3.0140	1.6005	3.01	(151)	γ -Fe ₂ O ₃
	63.093	7.7440	1.4723	1.20	(044)	γ -Fe ₂ O ₃

Table 2. The structural parameters of Fe₂O₃@Ag/AgCl NPs.

Samples	2 θ (Deg.)	FWHM (Deg.)	d _{hkl} Exp.(Å)	C.S (nm)	hkl	Phase
Fe ₂ O ₃ @Ag/AgCl	33.0304	0.40883	2.7098	20.28	104))	α -Fe ₂ O ₃
	35.4724	0.29224	2.5286	28.55	(110)	α -Fe ₂ O ₃
	37.8594	0.28982	2.3745	28.99	(111)	Ag
	44.0194	0.22642	2.0554	37.86	(002)	Ag
	49.3434	0.32336	1.8454	27.05	(20-4)	α -Fe ₂ O ₃
	54.7554	0.36059	1.6751	24.82	(116)	α -Fe ₂ O ₃
	57.2744	0.49481	1.6073	18.30	(21-2)	α -Fe ₂ O ₃
	62.3784	0.47547	1.4875	19.54	(214)	α -Fe ₂ O ₃
	64.2154	0.50914	1.4493	18.43	(300)	α -Fe ₂ O ₃
	27.5854	0.25049	3.2310	32.67	(111)	Ag Cl
	32.0074	0.22254	2.7940	37.15	(200)	Ag Cl
	45.9994	0.30576	1.9715	28.24	(220)	Ag Cl
	67.2514	0.30342	1.3910	31.45	(400)	Ag Cl
	76.5574	0.59207	1.2434	17.10	(420)	Ag Cl

nealing process and high availability of precursor ions further contribute to this increase.^{18,27} The average crystal size of Ag/AgCl was also calculated and found to be 33.20 and 29.32 nm, respectively. This increase in crystallite size of the shell compared to the core is primarily due to the intrinsic crystallization tendency of Ag/AgCl, the annealing conditions favoring its growth, and the availability of silver and chloride ions. In contrast, Fe₂O₃ core retains smaller crystallite size due to lattice strain and prior partial crystallization before annealing.^{28,29}

$$D = K\lambda/\beta\cos\theta \quad (3)$$

TEM characterization

TEM image (A) in Fig. 2 of Fe₂O₃ NPs prepared using mint leaf extract as a natural reductant and particle stabilizer revealed a heterogeneous structure composed of dense nanoclusters. A clear contrast in shading was observed between light and dark regions within the cluster, which is attributed to differences in the thickness or electron density of the particles, as well as the possible presence of different crystalline phases, this is in agreement with the study.³⁰ The image also showed that the nanoparticles had a quasi-spherical to irregular shape, with a clear tendency to aggregate into nanoclusters, which may be

attributed to the nature of the biosynthesis using the plant extract, in addition to the effect of the annealing conditions.³¹

While TEM image (B) showed nanoparticles with a homogeneous, stereoscopic shell structure around the nucleus, with the shell taking a regular spherical shape. The nucleus was represented by dark particles, attributed to iron oxide (Fe₂O₃), while a brighter layer, attributed to the Ag/AgCl composition, surrounded them.¹⁸ The uniform distribution of the shell around the nucleus in all directions reflects the successful formation of a homogeneous, three-dimensional spherical shell completely surrounding the nucleus. This configuration indicates the high stability of the nanoparticles and the effectiveness of the Fe₂O₃ coating process with Ag/AgCl, which is attributed to the homogeneous distribution of silver and chloride ions after annealing at 600 °C. This regular spherical structure enhances the physical and surface properties of the particles.³²

EDX characterization

EDX analysis in Fig. 3 (A) revealed that the primary composition of the sample was iron and oxygen, confirming the formation of Fe₂O₃. Carbon was also detected, attributed to residual organic components in the mint leaf extract used as a reducing agent

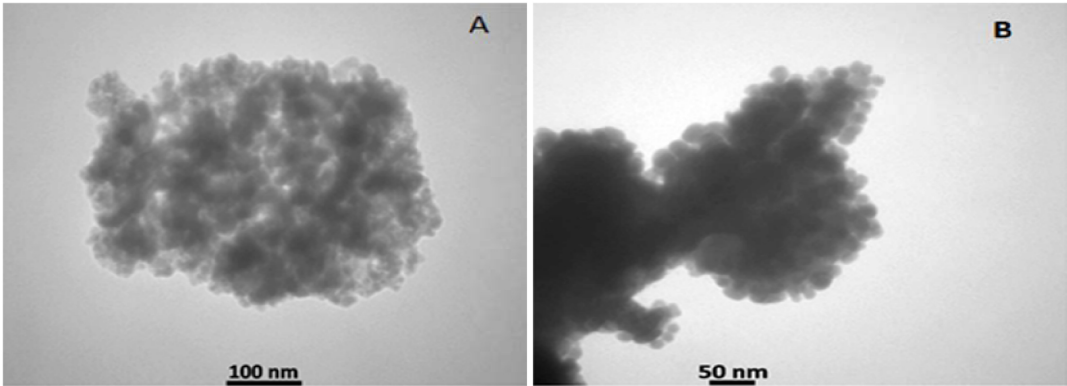


Fig. 2. A) TEM image for Fe_2O_3 and B) TEM image for $\text{Fe}_2\text{O}_3 @ \text{Ag}/\text{AgCl}$ NPs.

and stabilizer.³³ Minor elements, such as silicon and phosphorus, appeared in trace amounts and are likely natural traces in the plant extract. These minor elements do not affect the identity of the nanomaterial but indicate the role of the plant extract as a source of additional surface-active elements.¹⁶

In Fig. 3 (B) of $\text{Fe}_2\text{O}_3 @ \text{Ag}/\text{AgCl}$ sample also revealed the presence of Fe, O, in addition to Ag, Cl, and minor elements such as Na, P, and S due to the natural components of the mint leaf extract used in the biosynthesis. The iron and oxygen peaks are due to the core composed of Fe_2O_3 , while the silver and chlorine peaks indicate the formation of an outer shell of Ag and AgCl as a result of the combination of Ag^+ ions with Cl^- available in the plant medium after annealing. The silver content was higher than iron, indicating that the shell had formed densely or continuously around the core, or that the silver nitrate concentration used was sufficient to form a relatively silver-rich layer.^{34,35} The weight and atomic ratios of the elements are shown in a Table 3. The atomic ratio of silver (13.32%) compared to iron (21.60%) indicates that the Ag/AgCl shell is thin rather than thick, because in the case of a thick shell the silver ratio is clearly higher than iron or completely dominates the spectrum, while the presence of a strong iron signal means that the EDS beam is still penetrating the shell and reaching the core (Fe_2O_3).³⁶

FTIR characterization

The spectrum of FTIR as shown in Fig. 4 Fe_2O_3 and $\text{Fe}_2\text{O}_3 @ \text{Ag}/\text{AgCl}$ NPs shows several distinct peaks, reflecting both the iron oxide structure and the residual organic components of the extract. In Fe_2O_3 NPs, 3435.50 cm^{-1} appeared a broad peak indicating the stretching vibrations of O–H group, and the presence of surface hydroxyl groups or adsorbed water, the weaker absorption peak (i.e., higher transmittance) in

Table 3. The weight and atomic ratios of the elements for Fe_2O_3 and $\text{Fe}_2\text{O}_3 @ \text{Ag}/\text{AgCl}$ NPs.

Samples	Element	Wt.%	Atomic %
Fe_2O_3	C	3.04	7.74
	O	27.45	52.44
	Si	1.82	1.98
	P	1.59	1.56
	Fe	65.91	36.06
Samples	Element	Wt%	Atomic %
$\text{Fe}_2\text{O}_3 @ \text{Ag}/\text{AgCl}$	O	22.43	54.27
	Na	0.22	0.36
	Si	0.92	1.27
	P	1.21	1.52
	S	0.19	0.23
	Cl	6.53	7.13
	Fe	31.17	21.60
	Ag	37.12	13.32

$\text{Fe}_2\text{O}_3 @ \text{Ag}/\text{AgCl}$ NPs suggests a possible reduction or absence of hydroxyl groups or adsorbed water on the surface, likely due to the Ag/AgCl coating that prevents surface interactions.³⁷ 2956.38 , 2924.31 , and 2853.72 cm^{-1} peaks associated with C–H stretching vibrations, which may be due to organic compounds present in the mint extract, even after the sample was annealed, while these peaks appeared with less intense compared to Fe_2O_3 sample, indicating the reduction of organic groups on the surface or due to the coverage of the nanoparticle surface by the Ag/AgCl-based coating.³⁸ 1743.37 cm^{-1} attributed to carbonyl vibrations (C=O), which due to phenolic compounds or organic acids present in the extract, but this peak appeared weak, may be indicating the reduction or occlusion of organic compounds bearing carbonyl groups by the metal coating.³⁹ 1632.21 cm^{-1} bending vibrations of O–H group ($\delta\text{-OH}$), indicating the presence of adsorbed surface water even after annealing for Fe_2O_3 NPs.⁴⁰ 1465.38 , 1384.78 and 1632 cm^{-1} relating to C–H bending vibrations, indicating the presence of organic matter with some slight changes in intensity for $\text{Fe}_2\text{O}_3 @ \text{Ag}/\text{AgCl}$ NPs.

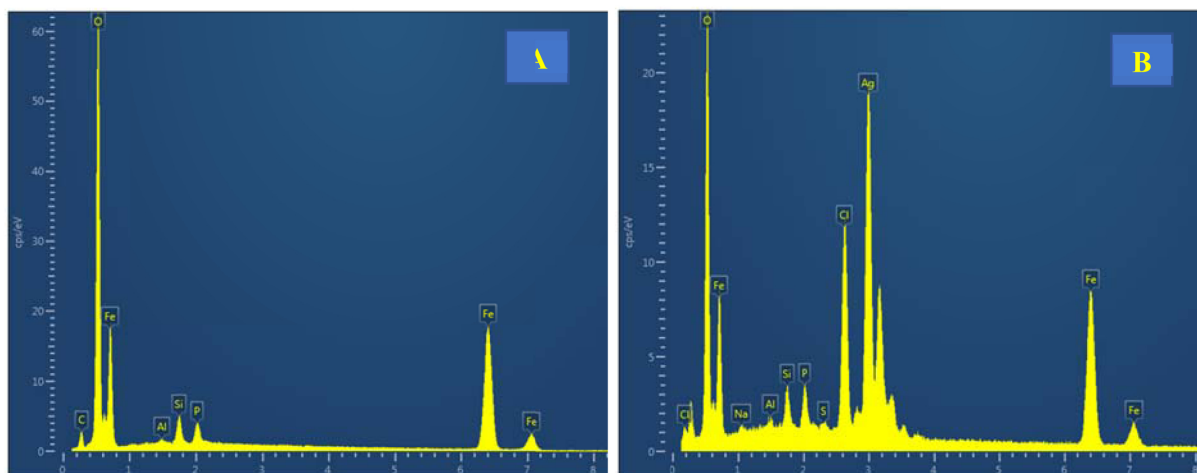


Fig. 3. EDX analysis for A) Fe_2O_3 and B) $\text{Fe}_2\text{O}_3 @ \text{Ag}/\text{AgCl}$ NPs.

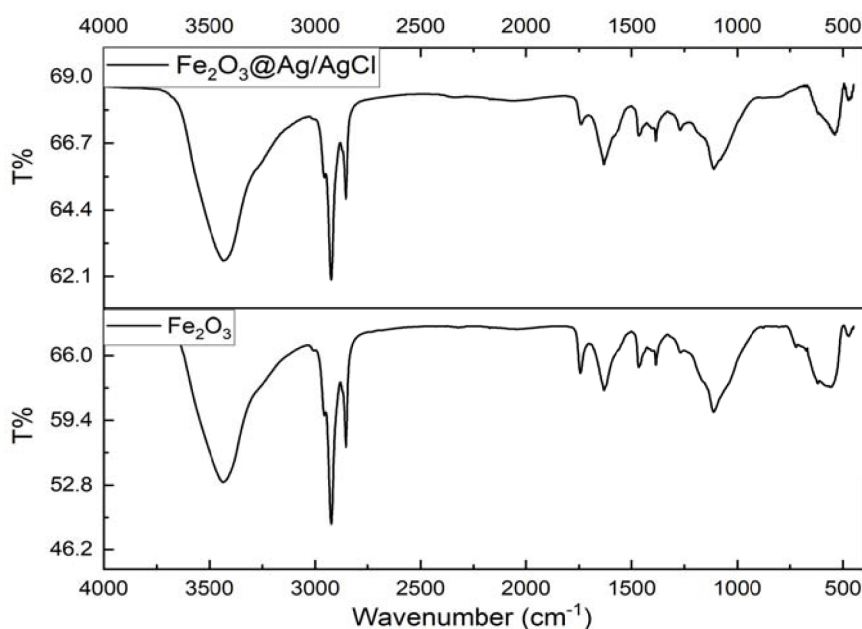


Fig. 4. FTIR analysis for Fe_2O_3 and $\text{Fe}_2\text{O}_3 @ \text{Ag}/\text{AgCl}$ NPs.

1112.15 cm^{-1} may be due to C–O or C–N vibrations, and are associated with plant compounds of the flavonoid or sugar type.⁴¹ 559.56 and 472.05 cm^{-1} represent stretching vibrations of Fe–O bond, which are characteristic peaks of iron oxides (Fe_2O_3) with these peaks continuing to appear strongly for $\text{Fe}_2\text{O}_3 @ \text{Ag}/\text{AgCl}$ NPs, confirming the presence of a stable iron oxide structure after coating.⁴² The absence of characteristic peaks for silver chloride is due to its ionic nature, which is not usually seen in FTIR.⁴³

AFM result

A comparison of Fe_2O_3 NPs (Image A) and $\text{Fe}_2\text{O}_3 @ \text{Ag}/\text{AgCl}$ NPs (Image B) reveals clear effects on morphological and surface properties as shown in Fig. 5. In Image A, Fe_2O_3 NPs has a smaller average grain size of 39 nm and a high surface roughness of 12 nm, indicating a more heterogeneous surface structure and irregular elevations. On the other hand, Image B shows that silver and silver chloride coatings increased the average grain size to 58 nm and reduced

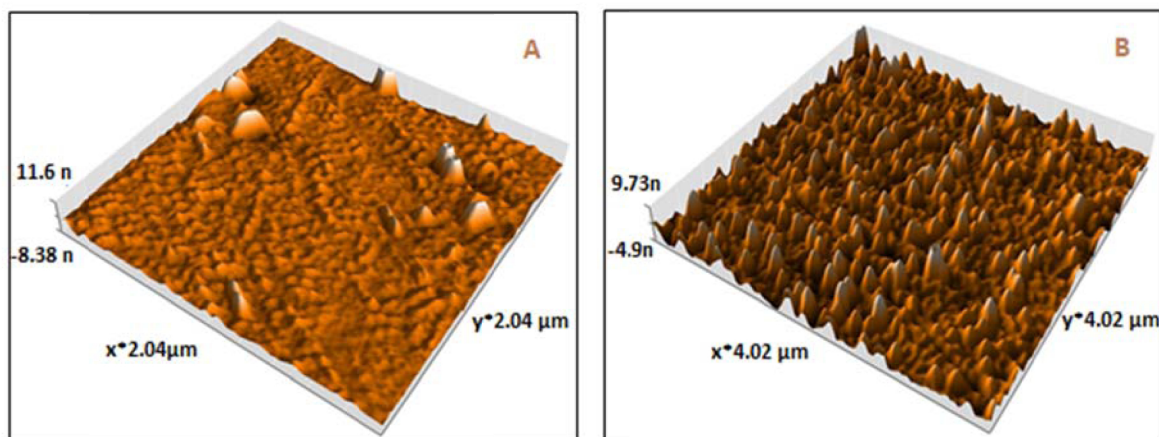


Fig. 5. AFM image for A) Fe_2O_3 NPs and B) $\text{Fe}_2\text{O}_3 @ \text{Ag/AgCl}$ NPs.

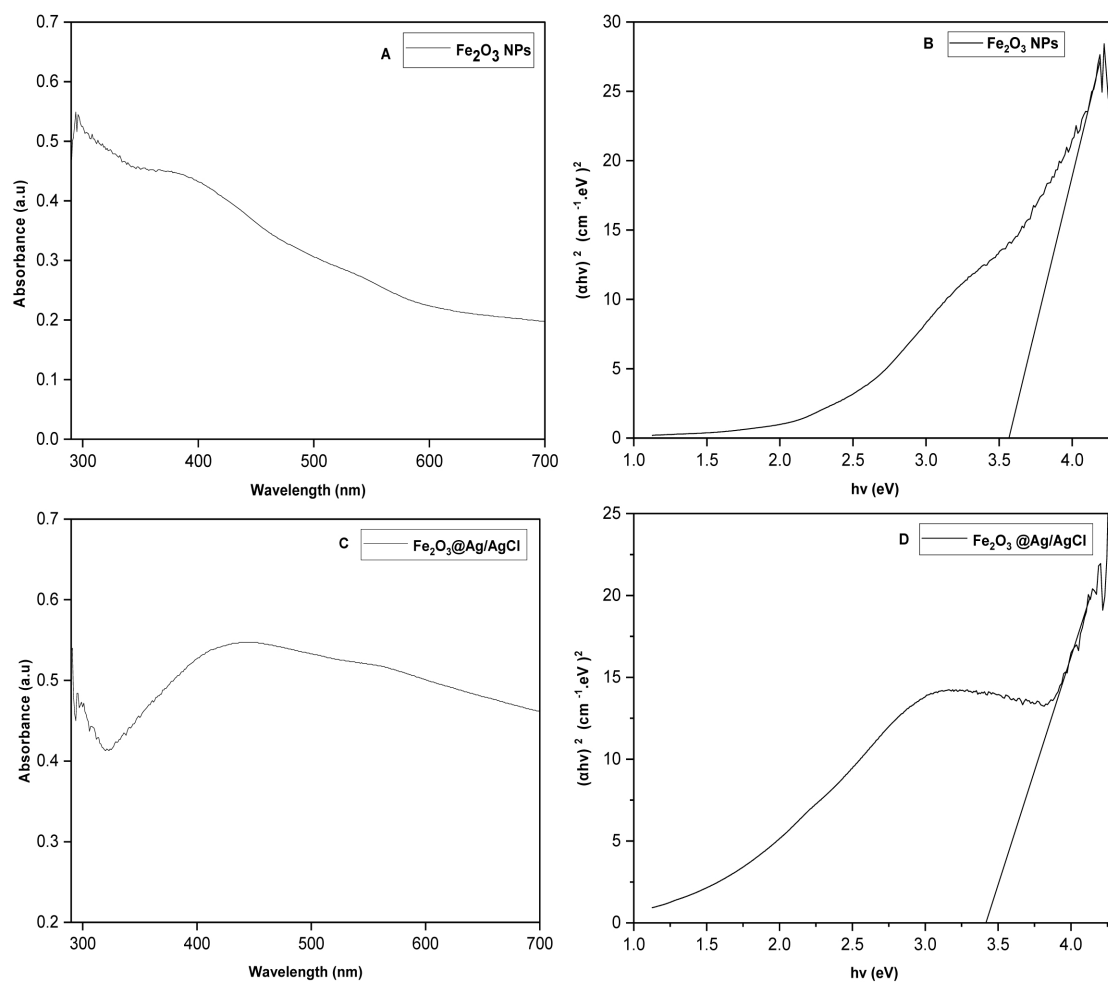


Fig. 6. A) The absorption spectrum of Fe_2O_3 and B) Tauc plot analysis of Fe_2O_3 NPs. C) The absorption spectrum of $\text{Fe}_2\text{O}_3 @ \text{Ag/AgCl}$ and D) Tauc plot analysis of $\text{Fe}_2\text{O}_3 @ \text{Ag/AgCl}$.

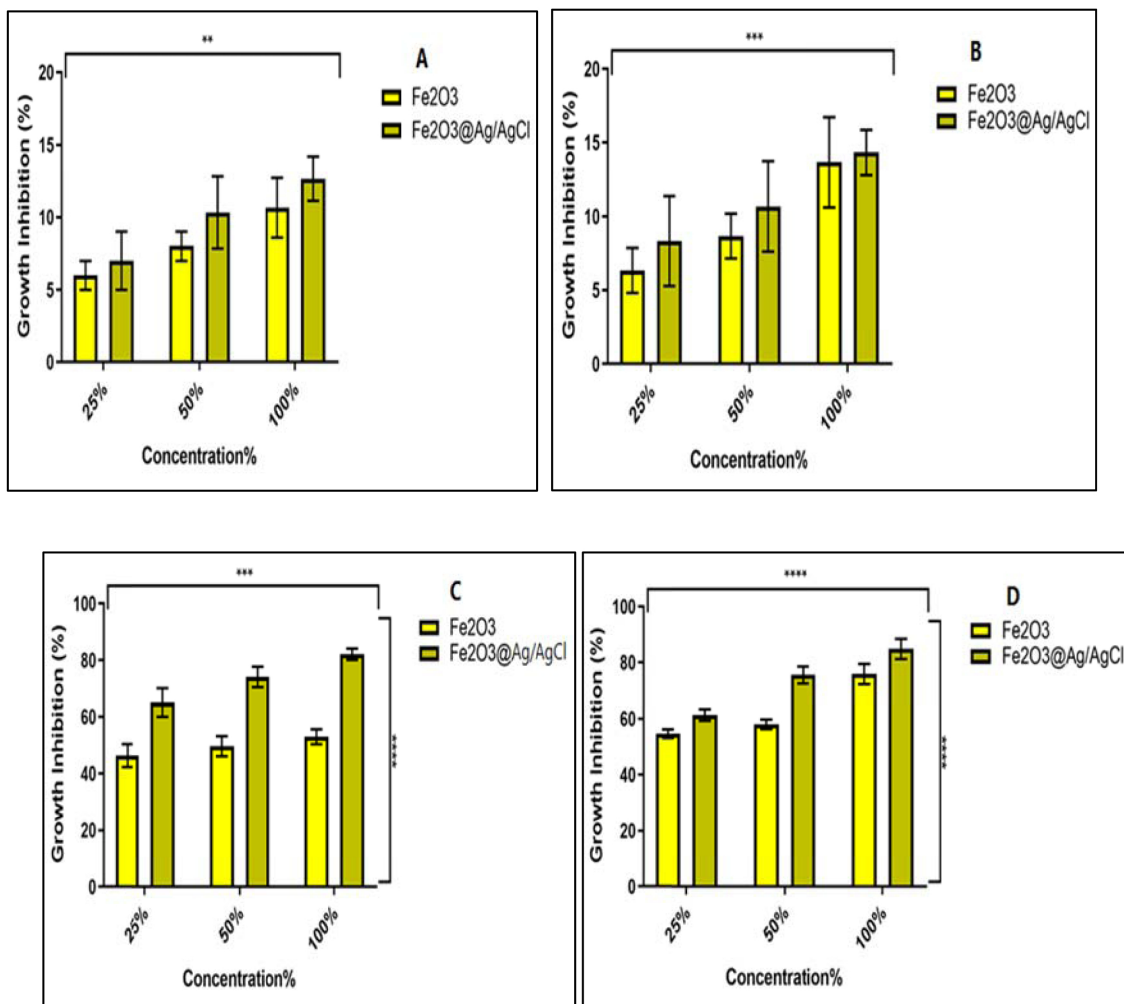


Fig. 7. A) Cytotoxicity assay on REF after 24 h and B) Cytotoxicity assay on REF after 48 h, C) Anticancer activity on MDA after 24 h and D) Anticancer activity on MDA after 48 h. Statistical significance levels are denoted by stars: ** $P \leq 0.01$, *** $P \leq 0.001$, and **** $P \leq 0.0001$.

the surface roughness to 3 nm, resulting in a smoother and denser surface. This change in surface structure reflects the effect of the metal coatings in improving surface stability and reducing elevation variation, this is an agreement with.^{44,45}

UV-Visible absorbance result

The optical properties of Fe₂O₃ NPs were studied using UV-Vis spectroscopy and Tauc plot analysis as shown in Fig. 6 A and B. The absorption spectrum is characterized by an absorption band in the UV region, gradually decreasing towards the visible region, indicating electronic transitions from the valence band to the conduction band, confirming the semiconducting nature of the material. The Tauc plot showed a direct energy gap calculated using the Tauc equation Eq. (4) of about 3.57 eV, which can be explained by the quantum confinement effect resulting from the small particle size.^{46,47} When Fe₂O₃ was coated

with silver and silver chloride (Fe₂O₃@Ag/AgCl) as shown in Fig. 6 C and D, the absorption spectrum showed a broad band extending from the UV to the visible region, and the direct energy gap was calculated as 3.41eV, this agreement with.⁴⁸ The additional absorption is attributed to the surface plasmon resonance (SPR) phenomenon caused by the presence of metallic silver particles, while the extension towards longer wavelengths indicates a synergy between Fe₂O₃, AgCl, and Ag⁰ that leads to enhanced light absorption and improved charge transport.²¹

$$(\alpha h\nu)^r = B (h\nu - E_g) \quad (4)$$

The effect of Fe₂O₃ and Fe₂O₃@Ag/AgCl NPs On REF and MDA cell line

The effect of Fe₂O₃ and Fe₂O₃@Ag/AgCl on REF cells was evaluated over two periods 24 hours and 48 hours, as shown in Fig. 7 (A and B). The results

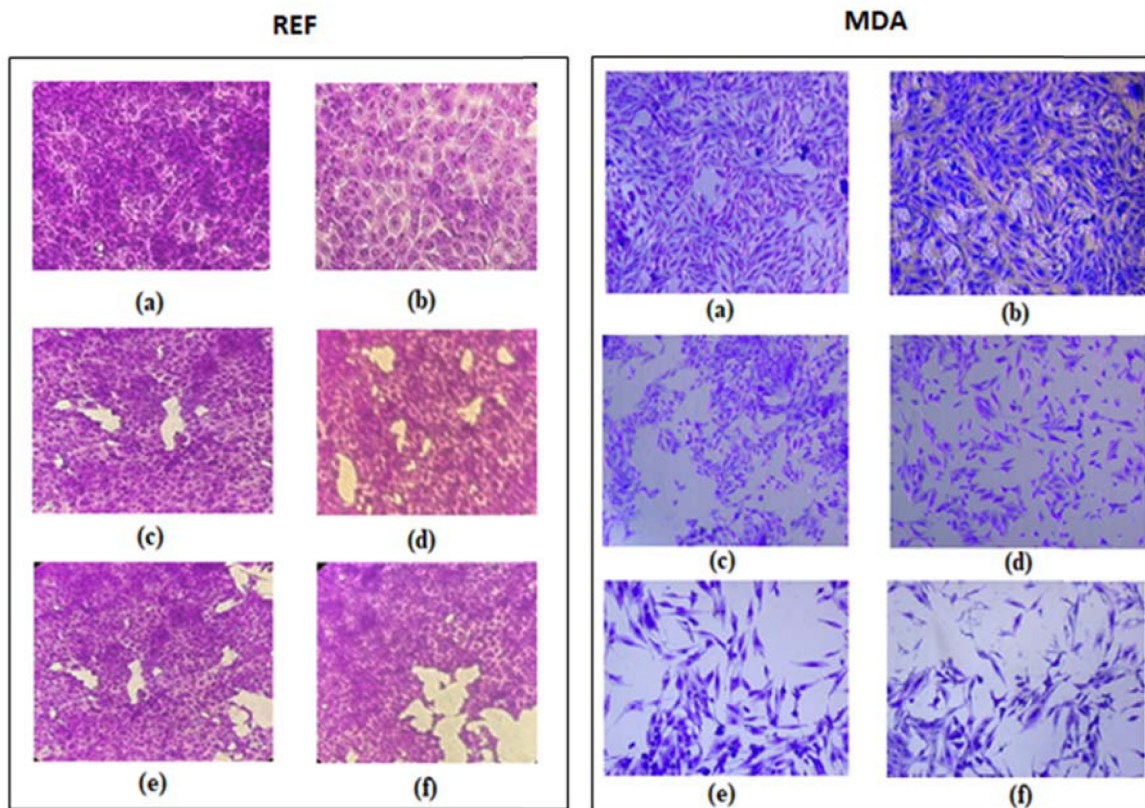


Fig. 8. Refers to microscopic images of normal cells (REF) and cancer cells (MDA), a) and b) refers to negative control of REF and MDA at 24 and 48 hours, respectively, while c) and d) indicates REF and MDA exposed to Fe_2O_3 NPs and $\text{Fe}_2\text{O}_3@Ag/AgCl$, respectively at 24 hours with concentration (100%), e) and f) indicates REF and MDA exposed to Fe_2O_3 NPs and $\text{Fe}_2\text{O}_3@Ag/AgCl$, respectively at 48 hours with concentration (100%).

showed that Fe_2O_3 at different concentrations (25%, 50%, and 100%) had a growth-inhibiting effect, with a significant increase ($P \leq 0.01$) after coating at 24 hours. The effect was greater with a significant increase ($P \leq 0.001$) after 48 hours. This inhibition is due to the oxidative effects of iron oxide particles, but the toxicity levels remain within safe limits and are non-toxic to REF cells according to the concentrations used in the experiment, and the mint leaf extract used in the preparation of nanoparticles also helps stabilize the particles and reduces overall toxicity.⁶ In contrast, $\text{Fe}_2\text{O}_3@Ag/AgCl$ appear to have a greater effect on normal cells than Fe_2O_3 alone. This greater effect may be due to the synergistic role of iron oxide, silver, and silver chloride. Furthermore, the interaction of iron oxide with silver and silver chloride may contribute to greater chemical interactions with normal cells than iron oxide alone.⁴⁹

$\text{Fe}_2\text{O}_3@Ag/AgCl$ were shown to be more effective with a significant increase ($P \leq 0.0001$) in inhibiting cancer cell growth than Fe_2O_3 at all concentrations

(25%, 50%, and 100%) and time periods (24 and 48) hours, as shown in Fig. 7 (C and D). Iron oxide nanoparticles contribute to improved particle accumulation within cancer cells due to their magnetic properties, allowing greater direction of the particles to target areas and thus increasing the effect of free radicals on cancer cells.⁵⁰ The results also showed that the effect of Fe_2O_3 increases after 48 hours, especially at the highest concentration of 100%, demonstrating that the interaction between the nanoparticles and cancer cells increases over time.⁵¹ Fig. 8 refers to microscopic images of normal cells (REF) and cancer cells (MDA), a) and b) refers to negative control of REF and MDA at 24 and 48 hours, respectively, while c) and d) indicates REF and MDA exposed to Fe_2O_3 NPs and $\text{Fe}_2\text{O}_3@Ag/AgCl$, respectively at 24 hours with concentration (100%), also (e and f) indicates REF and MDA exposed to Fe_2O_3 NPs and $\text{Fe}_2\text{O}_3@Ag/AgCl$, respectively at 48 hours with concentration (100%), where it was noted that there was a decrease in the number density of cells with the effect of the cell envelope.

Conclusion

The study successfully prepared Fe_2O_3 and $\text{Fe}_2\text{O}_3@\text{Ag}/\text{AgCl}$ NPs using a green method by mint leaf extract. The success of the encapsulation and its effect on the particle properties were confirmed using different techniques. XRD results showed that the Fe_2O_3 before encapsulation contained $\gamma\text{-Fe}_2\text{O}_3$ and $\alpha\text{-Fe}_2\text{O}_3$ phases, while after encapsulation, the $\alpha\text{-Fe}_2\text{O}_3$ phase became the dominant phase, indicating the stability of the phase after encapsulation. TEM images also revealed a uniform distribution of the Ag/AgCl outer layer around the Fe_2O_3 core, reflecting the success of the encapsulation process. On the other hand, EDX analysis showed that the components of the mint extract remained even after annealing at 600 °C, reflecting the extract's role in stabilizing the particles. As for FTIR, the peaks associated with Fe–O bonds showed stability after encapsulation, confirming the stability of the Fe_2O_3 core structure. AFM images also showed a significant decrease in surface roughness from 12 nm to 3 nm after encapsulation, reflecting improved particle stability. Fe_2O_3 showed UV absorption with a band gap of 3.57 eV, while $\text{Fe}_2\text{O}_3@\text{Ag}/\text{AgCl}$ exhibited two absorptions in the UV and visible regions with an increased band gap of 3.41 eV. Regarding biological activity, Fe_2O_3 NPs showed lower toxicity on REF for both 24 and 48 h compared to $\text{Fe}_2\text{O}_3@\text{Ag}/\text{AgCl}$, reflecting their ability to maintain cell stability under experimental conditions. While, cytotoxicity tests showed that the $\text{Fe}_2\text{O}_3@\text{Ag}/\text{AgCl}$ NPs were more effective against breast cancer cells (MDA) than Fe_2O_3 NPs with a more pronounced effect after 48 hours, reflecting the enhanced chemical reactivity of Ag/AgCl encapsulated particles against cancer cells.

Acknowledgment

We thank the cooperation of the Nanotechnology Laboratory at the University of Baghdad, College of Science for Women, Department of Physics.

Authors' declaration

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are ours. Furthermore, any Figures and images that are not ours have been included with the necessary permission for republication, which is attached to the manuscript.
- No animal studies are present in the manuscript.
- No human studies are present in the manuscript.

- Ethical Clearance: The project was approved by the local ethical committee at University of Baghdad.

Authors' contributions statement

R.A. UL and N.K. AB contributed to the study research proposal, preparation and description of the results.

Journal declaration

The Second author (N.K.A.) is an editor for the journal but did not participate in the peer review process other than as an author. The authors declare no other conflict of interest

References

1. Hilmi TA, Al-Ansari RA. Studying the effect of non-thermal plasma on the structure, optical, and humidity sensor properties of Cr:Se thin films. *Iraqi J Phys.* 2025;23(2):106–117. <https://doi.org/10.30723/ijp.v23i2.1340>.
2. Karnwal A, Jassim AY, Mohammed AA, Sharma V, Al-Tawaha ARMS, Sivanesan IJP. Nanotechnology for healthcare: plant-derived nanoparticles in disease treatment and regenerative medicine. *Pharmaceutics.* 2024;17(12):1711. <https://doi.org/10.3390/ph17121711>.
3. Attia NF, Abd El-Monaem EM, El-Aqapa HG, Elashery SE, Eltaweil AS, El Kady M, *et al.* Iron oxide nanoparticles and their pharmaceutical applications. *Appl Surf Sci Adv.* 2022;11:100284. <https://doi.org/10.1016/j.apsadv.2022.100284>.
4. Fahim YA, Hasani IW, Mahmoud Ragab WJEJoMR. Promising biomedical applications using superparamagnetic nanoparticles. *Eur J Med Res.* 2025;30(1):441. <https://doi.org/10.1186/s40001-025-02696-z>.
5. Salehizroveh M, Dehghani P, Mijakovic IJJoFB. Synthesis, functionalization, and biomedical applications of iron oxide nanoparticles (IONPs). *PRJ.* 2024;15(11):340. <https://doi.org/10.3390/jfb15110340>.
6. Nagaraj A, Ghosh OSN, Ghneim HK, AlSheikh YA, Mohammed K, Poda S. Fe_2O_3 -type iron oxide nanoparticles from Aerva lanata leaf extract exhibit antibiofilm, discriminatory toxicity in cancer cells, and theranostic against oxidative stress in zebrafish. *Chemical Phys Impact.* 2025;10:100849. <https://doi.org/10.1016/j.chphi.2025.100849>.
7. Sharma A, Aggarwal N, Panwar RS, Raja V, Ali D, Alarifi S. Magnetically separable Mangifera indica leaf extract-mediated hematite nanoparticles potentiate cytotoxic activity. *J Mol Struct.* 2025;1324:140745. <https://doi.org/10.1016/j.molstruc.2024.140745>.
8. Mohamed AT, Hameed RA, El-Moslami SH, Fareid M, Othman M, Loutfy SA. Facile synthesis of Fe_2O_3 , $\text{Fe}_2\text{O}_3@\text{CuO}$ and WO_3 nanoparticles: characterization, structure determination and evaluation of their biological activity. *Sci Rep.* 2024;14:6081. <https://doi.org/10.1038/s41598-024-55319-8>.
9. Gawande MB, Goswami A, Asefa T, Guo H, Biradar AV, Peng D-L. Core-shell nanoparticles: synthesis and

- applications in catalysis and electrocatalysis. *Chem Soc Rev.* 2015;44(21):7540–7590. <https://doi.org/10.1039/C5CS00343A>.
10. González-Fernández S, Blanco-Agudín N, Rodríguez D, Fernández-Vega I, Merayo-Llodes J, Quirós LM. Silver nanoparticles: a versatile tool against infectious and non-infectious diseases. *Antibiotics.* 2025;14(3):289. <https://doi.org/10.3390/antibiotics14030289>.
 11. Ghosh U, Sayef Ahammed K, Mishra S, Bhaumik A. The emerging roles of silver nanoparticles to target viral life cycle and detect viral pathogens. *Chem Asian J.* 2022;17(5):e202101149. <https://doi.org/10.1002/asia.202101149>.
 12. Kashid Y, Ghotekar S, Bilal M, Pansambal S, Oza R, Varma RS, *et al.* Bio-inspired sustainable synthesis of silver chloride nanoparticles and their prominent applications. *J Indian Chem Soc.* 2022;99(5):100335. <https://doi.org/10.1016/j.jics.2021.100335>.
 13. Al-Hakkani MF, Gouda GA, Hassan SHA. A review of green methods for phyto-fabrication of hematite (α -Fe₂O₃) nanoparticles and their characterization, properties, and applications. *Heliyon.* 2021;7(1):e05806. <https://doi.org/10.1016/j.heliyon.2020.e05806>.
 14. Ahmad W, Joshi HC, Pandey S, Kumar V, Verma M. An overview of green methods for Fe₂O₃ nanoparticle synthesis and their applications. *Int Nano Lett.* 2023;13(2):117–130. <https://doi.org/10.1007/s40089-022-00386-w>.
 15. Thanasakongpong A, Ksapabutr B, Panapoy M. Microwave-assisted green synthesis of silver nanoparticles using extract of mint leaves. *IOP Conf Ser: Mater Sci Eng.* 2023;1280(1):012016. <https://doi.org/10.1088/1757-899X/1280/1/012016>.
 16. Yousaf R, Zain M, Ijaz UJAAS. Green synthesis and evaluation of Mentha piperita-mediated iron nanoparticles for in vitro antibacterial activity. *J Xi'an Shiyu Univ Nat Sci Ed.* 2024;20(8):653–663.
 17. Archana V, Joseph Prince J, Kalainathan S. Simple one-step leaf extract-assisted preparation of α -Fe₂O₃ nanoparticles, physicochemical properties, and its sunlight-driven photocatalytic activity on methylene blue dye degradation. *J Nanomater.* 2021;2021(1):8570351. <https://doi.org/10.1155/2021/8570351>.
 18. Sarani M, Hamidian K, Barani M, Adeli-Sardou M, Khonakdar HA. α -Fe₂O₃@Ag and Fe₃O₄@Ag core-shell nanoparticles: green synthesis, magnetic properties and cytotoxic performance. *ChemOpen.* 2023;12(6):e202200250. <https://doi.org/10.1002/open.202200250>.
 19. Adil BH, Al-Shammari AM, Murbat HH. Breast cancer treatment using cold atmospheric plasma generated by the FE-DBD scheme. *Clin Plasma Med.* 2020;19:100103. <https://doi.org/10.1016/j.cpm.2020.100103>.
 20. Jassim DR, Adil BH, Al-Ansari RA. Inhibition of breast cancer by (Cu-Se) nanoparticles generated by plasma jet. *J Theor Appl Phys.* 2024;18(2). <https://doi.org/10.57647/j.jtap.2024.1802.26>.
 21. Xu Y, Huang S, Xie M, Li Y, Jing L, Xu H. Core-shell magnetic Ag/AgCl@Fe₂O₃ photocatalysts with enhanced photoactivity for eliminating bisphenol A and microbial contamination. *New J Chem.* 2016;40(4):3413–3422. <https://doi.org/10.1039/C5NJ02898A>.
 22. Sharifi-Rad M, Pohl P. Synthesis of biogenic silver nanoparticles (AgCl-NPs) using *Pulicaria vulgaris* Gaertn. aerial part extract and their application as antibacterial, antifungal and antioxidant agents. *Nanomaterials.* 2020;10(4):638. <https://doi.org/10.3390/nano10040638>.
 23. Asefian S, Ghavam M. Green and environmentally friendly synthesis of silver nanoparticles with antibacterial properties from some medicinal plants. *BMC Biotechnol.* 2024;24(1):5. <https://doi.org/10.1186/s12896-023-00828-z>.
 24. Mohammad SJ, Hassan TB, Ali HM. Structural and optical properties of iron oxide α -Fe₂O₃ nanowires prepared by hydrothermal method. *AIP Conf Proc.* 2023;2899:060003. <https://doi.org/10.1063/5.0157593>.
 25. Xu G, Yang L, Li J, Liu C, Xing W, Zhu J. Strategies for improving stability of Pt-based catalysts for oxygen reduction reaction. *Adv Sens Energy Mater.* 2023;2(2):100058. <https://doi.org/10.1016/j.asems.2023.100058>.
 26. Shaker DS, Abass NK, Ulwali RA. Preparation and study of the Structural, Morphological and Optical properties of pure Tin Oxide Nanoparticle doped with Cu. *Baghdad Sci J.* 2022;19(3):660. <https://doi.org/10.21123/bsj.2022.19.3.0660>.
 27. Lin T, Xie C, Mi S, Liang D, Huang H, Xie J. Study on the effects of precursor concentration and annealing process of In₂O₃ thin films prepared by sol-gel method. *J Electron Mater.* 2024;58(7):585–596. <https://doi.org/10.1134/S1063782624600840>.
 28. Mahmed N, Jiang H, Heczko O, Söderberg O, Hannula S-P. Influence of different synthesis approaches on doping behavior of silver nanoparticles onto iron oxide–silica core–shell surfaces. *J Nanopart Res.* 2012;14:1–15. <https://doi.org/10.1007/s11051-012-0987-1>.
 29. Yen FS, Chen WC, Yang JM, Hong CT. Crystallite size variations of nanosized Fe₂O₃ powders during γ -to- α phase transformation. *Nano Lett.* 2002;2(3):245–252. <https://doi.org/10.1021/nl010089m>.
 30. Tian R, Gao Z, Lang R, Li N, Gu H, Chen G, *et al.* Ru-functionalized Ni-doped dual phases of α/γ -Fe₂O₃ nanosheets for an optimized acetone detection. *J Nanostruct Chem.* 2023;13(6):577–589. <https://doi.org/10.1007/s40097-022-00475-4>.
 31. Dar M, Ansari S, Wahab R, Kim YS, Shin HS, eds. The synthesis of maghemite and hematite (γ -Fe₂O₃, α -Fe₂O₃) nanospheres. *Mater Sci Forum.* 2007;534–536:534–536. <https://doi.org/10.4028/www.scientific.net/MSF.534-536>.
 32. Rastgar M, Ghasemi Z, Samari F. Biosynthesis of magnetic ZnO@Fe₂O₃ nanocomposites decorated with Ag/AgCl using Hormoz Island's red soil and Avicennia marina leaf extract. *Sci Rep.* 2025;15(1):15110. <https://doi.org/10.1038/s41598-025-98442-w>.
 33. Mohamed A, Atta R, Kotp AA, Abo El-Ela FI, Abd El-Raheem H, Farghali A. Green synthesis and characterization of iron oxide nanoparticles for the removal of heavy metals (Cd²⁺ and Ni²⁺) from aqueous solutions with antimicrobial investigation. *Environ Sci Pollut Res.* 2023;13(1):7227. <https://doi.org/10.1038/s41598-023-31704-7>.
 34. Szydłowska-Czerniak A, Kowaluk A, Strzelec M, Sawicki T, Tańska M. Evaluation of bioactive compounds and chemical elements in herbs: effectiveness of choline chloride-based deep eutectic solvents in ultrasound-assisted extraction. *Molecules.* 2025;30(2):368. <https://doi.org/10.3390/molecules30020368>.
 35. Jyothsna S, Manjula G, Suthari S, Rao AN. Qualitative elemental analysis of selected potential anti-asthmatic medicinal plant taxa using EDXRF technique. *Heliyon.* 2020;6(2):e03456. <https://doi.org/10.1016/j.heliyon.2020.e03456>.
 36. Radnik J, Knigge X, Andresen E, Resch-Genger U, Cant DJ, Shard AG, *et al.* Composition, thickness, and homogeneity of the coating of core–shell nanoparticles—possibilities, limits, and challenges of X-ray photoelectron spectroscopy. *Anal Bioanal Chem.* 2022;414(15):4331–4345. <https://doi.org/10.1007/s00216-022-04057-9>.

37. Nayan MB, Jagadish K, Abhilash MR, Namratha K, Srikanthaswamy J. Comparative study on the effects of surface area, conduction band and valence band positions on the photocatalytic activity of ZnO–M_xO_y heterostructures. *J Water Resour Prot.* 2019;11(3):357. <https://doi.org/10.4236/jwarp.2019.113021>.
38. Das S, Das A, Thamarai Selvan R, Raj SA. The antibacterial and aroma finishing of cotton fabrics by *Mentha piperita* extract. *J Text Inst.* 2021;112(7):1181–1190. <https://doi.org/10.1080/00405000.2020.1805194>.
39. Bajrami DA, Ganiji A, Saiti-Musliji Z, Jordanovska S. A phytochemical analysis of mint and *Salvia officinalis* L. tea using FTIR technique. *Eur J Agric Food Sci.* 2023;5(4):55–59. <https://doi.org/10.24018/ejfood.2023.5.4.682>.
40. Khorshidi N, Azadmehr A. Characterisation and adsorption properties of oxalate-loaded hematite composite for Cd(II) and Pb(II) adsorption: equilibrium models, thermodynamic and kinetic studies. *Sep Sci Technol.* 2016;51(13):2122–2137. <https://doi.org/10.1080/01496395.2016.1205610>.
41. Ikhmal W, Yasmin M, Fazira M, Rafizah WA, Nik WBW, Sabri MGM, eds. Anticorrosion coating using *Olea* sp. leaves extract. *IOP Conf Ser Mater Sci Eng.* 2018;344:012028. <https://doi.org/10.1088/1757-899X/344/1/012028>.
42. Sajjad A, Hussain S, Jaffari GH, Hanif S, Qureshi MN, Zia M. Fabrication of hematite (α -Fe₂O₃) nanoparticles under different spectral lights transforms physicochemical, biological, and nanozymatic properties. *Nano Trends.* 2023;2:100010. <https://doi.org/10.1016/j.nwnano.2023.100010>.
43. Sultana N, Ruhul-Amin M, Hasan I, Kabir SR, Asaduzzaman A. Antibacterial, antioxidant, and anticancer effects of green synthesized silver/silver chloride nanoparticles using *Spondias pinnata* bark extract. *Food Chem Adv.* 2024;4:100709. <https://doi.org/10.1016/j.focha.2024.100709>.
44. González-Hernández A, Suárez-Domínguez EJ, Kulich EF, Morales-Cepeda AB. Relationship analysis of surface roughness measurements on coatings using AFM and fractal dimension by mesoscopic model methods. *Superficies y Vacío.* 2023;36. https://doi.org/10.47566/2023_syv36_1-230501.
45. Chen Y-C, Ou S-F, Tsai M-H. Enhancing surface quality in laser powder bed fusion using core-shell structured powder with micrometer-sized metal core and TiO₂ nanoparticle shell. *J Mater Res Technol.* 2025;35:6312–6321. <https://doi.org/10.1016/j.jmrt.2025.03.014>.
46. Alotaibi B, Al-Yousef H, Atta A, Rizk S, Elgendy A. Synthesis, structural characterization and optical studies of Fe₂O₃ nanoparticles based polymeric materials for flexible electronic devices. *Dig J Nanomater Bios.* 2024;19(2). <https://doi.org/10.15251/DJNB.2024.192.989>.
47. Abbas BH, Abdalameer NK, Mohammed RS. Synthesis of copper oxide nanostructures by Ar plasma jet and study of their structural and optical properties. *Iraqi J Sci.* 2024;65(3):1999–2006. <https://doi.org/10.24996/ij.s.2024.65.4.18>.
48. Tahir D, Ilyas S, Rahmat R, Heryanto H, Fahri AN, Rahmi MH. Enhanced visible-light absorption of Fe₂O₃ covered by activated carbon for multifunctional purposes: tuning the structural, electronic, optical, and magnetic properties. *ACS Omega.* 2021;6(42):28334–28346. <https://doi.org/10.1021/acsomega.1c04526>.
49. Comfort KK, Maurer EI, Braydich-Stolle LK, Hussain SM. Interference of silver, gold, and iron oxide nanoparticles on epidermal growth factor signal transduction in epithelial cells. *ACS Nano.* 2011;5(12):10000–10008. <https://doi.org/10.1021/nn203785a>.
50. Malhotra N, Lee J-S, Liman RAD, Ruallo JMS, Villaflores OB, Ger T-R, *et al.* Potential toxicity of iron oxide magnetic nanoparticles: a review. *Molecules.* 2020;25(14):3159. <https://doi.org/10.3390/molecules25143159>.
51. Calero M, Chiappi M, Lázaro-Carrillo A, Rodríguez MJ, Chichón FJ, Crosbie-Staunton K, *et al.* Characterization of interaction of magnetic nanoparticles with breast cancer cells. *J Nanobiotechnol.* 2015;13:1–15. <https://doi.org/10.1186/s12951-015-0073-9>.

تحضير وتوصيف جسيمات Fe_2O_3 و $\text{Fe}_2\text{O}_3@Ag/AgCl$ القلب والغلاف النانوية باستخدام مستخلص اوراق النعناع، ودراسة سميتها الخلوية وتثبيطها لخلايا سرطان الثدي

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الخلاصة

تم تحضير جسيمات أكسيد الحديد النانوية (Fe_2O_3) وجسيمات أكسيد الحديد ذات القلب المغلف بالفضة/كلوريد الفضة ($\text{Fe}_2\text{O}_3@Ag/AgCl$) بطريقة التخليق الأخضر باستخدام مستخلص أوراق النعناع. أظهرت نتائج حيود الأشعة السينية أن جسيمات Fe_2O_3 تكونت بطورين هما $\gamma\text{-Fe}_2\text{O}_3$ و $\alpha\text{-Fe}_2\text{O}_3$ ، في حين تكونت جسيمات $\text{Fe}_2\text{O}_3@Ag/AgCl$ بطور واحد فقط هو $\alpha\text{-Fe}_2\text{O}_3$ ، مع زيادة في حجم البلورات من 1.89 نانومتر لـ Fe_2O_3 إلى 22.42 نانومتر لـ $\text{Fe}_2\text{O}_3@Ag/AgCl$. كشفت صور المجهر الإلكتروني النافذ أن جسيمات Fe_2O_3 تمتلك بنية غير متجانسة تحتوي على تجمعات نانوية، بينما أظهرت جسيمات $\text{Fe}_2\text{O}_3@Ag/AgCl$ تغليفاً منتظماً من الفضة/كلوريد الفضة حول لب أكسيد الحديد، مما يدل على نجاح عملية التغليف. أظهر تحليل مطيافية الأشعة تحت الحمراء بتحويل فورييه قمماً تعود لروابط Fe-O عند 559.56 و 472.05 cm^{-1} ، إضافة إلى وجود مجاميع وظيفية ناتجة عن مكونات المستخلص النباتي. بينت نتائج مجهر القوة الذرية أن جسيمات $\text{Fe}_2\text{O}_3@Ag/AgCl$ تمتلك سطحاً أكثر نعومة وحجماً بلورياً أكبر (58 نانومتر) مقارنةً بجسيمات Fe_2O_3 (39 نانومتر)، مع انخفاض في خشونة السطح إلى 3 نانومتر مقارنةً بـ 12 نانومتر لـ Fe_2O_3 . أظهر تحليل الأشعة فوق البنفسجية-المرئية امتصاصاً في منطقة الأشعة فوق البنفسجية مع ظهور قمة بلازمونية في المجال المرئي، وكانت قيم فجوة الطاقة تساوي 3.57 إلكترون فولت لـ Fe_2O_3 و 3.41 إلكترون فولت لـ $\text{Fe}_2\text{O}_3@Ag/AgCl$. تم إجراء اختبار السمية الخلوية على خلايا الأرومة الليفية الجنينية الطبيعية للفئران، بالإضافة إلى اختبار تثبيط نمو خلايا سرطان الثدي باستخدام تركيز 50 ميكروغرام/مل مع سلسلة من التخفيفات (100%، 50%، 25%) ولمدتين زمنيتين (24 و 48 ساعة). أظهرت جسيمات $\text{Fe}_2\text{O}_3@Ag/AgCl$ سمية أعلى تجاه الخلايا الطبيعية، لكنها بقيت ضمن الحدود المسموح بها، كما أظهرت فعالية أكبر في تثبيط نمو خلايا سرطان الثدي مقارنةً بجسيمات Fe_2O_3 ، خصوصاً بعد 48 ساعة.

الكلمات المفتاحية: سرطان الثدي، السمية الخلوية، جسيمات أكسيد الحديد النانوية، Fe_2O_3 جسيمات أكسيد الحديد القلب والفضة / كلوريد الفضة الغلاف النانوية $\text{Fe}_2\text{O}_3@Ag/AgCl$ و الطريقة الخضراء.