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Study of The Structural and Magnetic Properties of Particlesfe$_3O_4$ Nanoparticles Modified Using Aqueous And Alcoholic Papaya Extracts With Chitosan Encapsulation

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Abstract :

In this research, particles were prepared.Fe_3O_4 nanoparticles were prepared using papaya extract in its aqueous and alcoholic forms, coated with varying proportions of chitosan (5%, 10%, 15%), with the aim of studying the effect of the nature of the extract and the proportion of chitosan on the structural, morphological and magnetic properties of the particles.

X-ray diffraction results showed(XRD) showed that all samples maintained the typical inverse cubic crystal structure of iron oxide Fe_3O_4. The highest crystal size was recorded in the samples prepared with the aqueous extract at 15% chitosan, reaching approximately 152.7 nm, while it decreased to 100.4 nm in the alcoholic samples at the same ratio, reflecting the ability of the alcoholic extract to inhibit crystal growth due to its effective surface interactions.

In morphological analysis using scanning electron microscopy(SEM) The alcoholic samples also showed smaller particle sizes of 67.0 nm, compared to 74.0 nm in the aqueous samples at 15% chitosan, demonstrating the effectiveness of the alcoholic extract in reducing particle size and enhancing their nanoscale distribution. TEM analysis supported these results, showing a gradual decrease in particle diameters to 10.1 nm in the alcoholic system, with a clear shift in shape toward regular spherical shape.

The magnetic properties measured by the techniqueVSM revealed ferromagnetic behavior for all samples, with the highest magnetic saturation recorded in the 5% alcohol chitosan sample, reaching 63.2 emu/g, while this value gradually decreased with increasing chitosan. In contrast, the highest magnetoresistance (Hc) was recorded in the 15% aqueous sample, reaching 140 Oe, demonstrating the bioencapsulation effect on resistance to remagnetization.

Keywords: Particles fe_3O_4 Nanoparticles, Papaya Extract, Chitosan, X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM, TEM), Magnetic Properties (VSM).

دراسة الخواص التركيبية والمغناطيسية لجسيمات Fe_3O_4 النانوية المعدلة باستخدام مستخلصي البابايا المائي والكحولي مع تغليف الكايتوسان

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مستخلص:

تم في هذا البحث تحضير جسيمات Fe_3O_4 النانوية باستخدام مستخلص البابايا بصيغتيه المائية والكحولية، مع تغليفها بنسب متفاوتة من الكايتوسان (٥٪، ١٠٪، ١٥٪)، وذلك بهدف دراسة تأثير طبيعة المستخلص ونسبة الكايتوسان على الخصائص التركيبية والمورفولوجية والمغناطيسية للجسيمات.

أظهرت نتائج حيود الأشعة السينية (XRD) أن جميع العينات حافظت على التركيب البلوري المكعب العكسي النمطي لأوكسيد الحديد Fe_3O_4. وقد تم تسجيل أعلى حجم بلوري في العينات المحضّرة بالمستخلص المائي عند نسبة ١٥٪ كايتوسان، حيث بلغ الحجم نحو 152.7 نانومتر، في حين انخفض إلى 100.4 نانومتر في العينات الكحولية عند نفس النسبة، مما يعكس قدرة المستخلص الكحولي على تثبيط النمو البلوري نتيجة تفاعلاته السطحية الفعّالة.

في التحليل المورفولوجي باستخدام المجهر الإلكتروني الماسح (SEM)، أظهرت العينات الكحولية أيضًا أصغر حجم حبيبي وصل إلى 67.0 نانومتر، مقارنةً بـ 74.0 نانومتر في العينات المائية عند نسبة كايتوسان ١٥٪، مما يدل على فعالية المستخلص الكحولي في تقليص حجم الجسيمات وتعزيز توزيعها النانوي. كما دعم تحليل TEM هذه النتائج، حيث أظهر انخفاضًا تدريجيًا في أقطار الجسيمات وصولًا إلى 10.1 نانومتر في النظام الكحولي، مع وضوح تام في انتظام الشكل نحو الكروية المنتظمة.

أما الخصائص المغناطيسية المقاسة بتقنية VSM فقد كشفت عن سلوك فيرومغناطيسي لجميع العينات، مع تسجيل أعلى تشبع مغناطيسي في العينة الكحولية بنسبة ٥٪ كايتوسان بلغ 63.2 emu/g، في حين تراجعت هذه القيمة تدريجيًا بزيادة الكايتوسان. في المقابل، سجلت أعلى مقاومة مغناطيسية (Hc) في العينة المائية بنسبة ١٥٪، حيث بلغت 140 Oe، مما يدل على تأثير التغليف الحيوي في مقاومة إعادة التمغنط..

الكلمات المفتاحية : جسيمات Fe_3O_4 النانوية، مستخلص البابايا، الكايتوسان، حيود الأشعة السينية المجهر الإلكتروني ، الخصائص المغناطيسية .

1-Introduction

Magnetic nanoparticles form a type Fe_3O_4 magnetite is a cornerstone of many advanced applications, particularly in biomedicine, drug delivery, magnetic resonance imaging, and environmental and industrial applications such as pollutant removal or magnetic catalysis. This interest is due to its unique properties, such as its nanoscale size, high surface properties, and ferromagnetic behavior at certain temperatures, which give it a high ability to interact within both physical and biological systems [1].

In recent years, researchers have turned to the use of biopreparation methods.(Bio-synthesis) as environmentally friendly alternatives that are safer than traditional physical and chemical methods, as these methods allow the synthesis of nanoparticles using plant extracts containing effective organic compounds such as phenols, flavonoids, terpenes, and alkaloids, which are substances capable of reducing and stabilizing metal ions without the need for toxic materials [2].

In this context, papaya is considered-Carica papaya is a plant source rich in these compounds. Numerous studies have shown that its extract, whether aqueous or alcoholic, has a high ability to stimulate the formation of nanoparticles, providing them with multiple functional properties [3]. Chitosan, a biopolymer derived from chitin, is widely used in nanoparticle encapsulation due to its positive charge, antibacterial properties, and excellent biocompatibility, which enhances particle stability and prevents aggregation [4].

On the other hand, the structural and magnetic properties of these particles play a crucial role in determining their functional performance. Using techniques such as X-ray diffraction(X-RD), the nature of the crystal phases can be studied and the crystal size can be accurately calculated, while scanning electron microscopy (SEM) and transmission microscopy (TEM) are used to reveal the shape, size and surface distribution of particles [5]. The technique of magnetic properties analysis (VSM) is used to understand the nature of magnetic behavior and determine important parameters such as magnetic saturation (Ms), remanent

magnetization (Mr) and coercive field (Hc), which are directly related to the particle size and surface composition [6].

2-Preparation method

2-1 Preparation of Pure Fe_3O_4 Particles

Fe_3O_4 nanoparticles were prepared using the co-precipitation method. Ferric chloride hexahydrate ($FeCl_3$ $6H_2O$, 99% purity, Sigma-Aldrich, Germany) and ferrous chloride heptahydrate ($FeSO_4$ $7H_2O$, 99% purity, Sigma-Aldrich, Germany) were dissolved in 100 mL of deionized water at a 1:2 molar ratio. The solution was then heated to 80°C using a magnetic stirrer (IKA, Germany) under nitrogen gas to prevent oxidation of the Fe_3^+ ions by atmospheric oxygen during the reaction.

The pH of the solution was adjusted and monitored using a pH meter (Hanna Instruments, USA), gradually increasing to pH = 11 by adding 2M sodium hydroxide solution prepared from NaOH granules (99% purity, Merck, Germany) using a drip funnel to ensure gradual addition of the base. As the pH increased, a black precipitate of Fe_3O_4 was formed, which was separated using a strong neodymium magnet, washed several times with distilled water and ethanol to remove impurities and unreacted ions, and finally dried in an electric oven (Memmert, Germany) at 60°C for 12 h.ed in an oven at 60°C for 12 h.

2-2 Preparation of Papaya Extract

Papaya extract was extracted using two different methods: aqueous and alcoholic extracts, as follows:

1. Aqueous Extract:

100 grams of dried papaya powder was placed in a Soxhlet extractor (Shanghai Shenshun Company, China) with 200 ml of distilled water. The extraction process continued for 1.5 hours at the boiling point of the water.

2. Alcoholic Extract:

This was performed using the same method as above, replacing the distilled water with 200 ml of absolute ethanol (99.9%, Merck Company, Germany). After extraction, both extracts were filtered using Whatman No. 1 filter paper to remove impurities. The extracted solutions were then stored in tightly sealed bottles in a refrigerator at 4–8°C until use.

Figure (1) Device(extractor Sexhlet)

2-3 Preparation of Fe_3O_4 Modified with Papaya Extract and Chitosan

Fe_3O_4 modified particles were prepared by adding papaya extract (either aqueous or alcoholic) and encapsulating them with chitosan according to the following steps:

1. Chitosan powder (purity ≥ 85%, Sigma-Aldrich, Germany) was dissolved in 1% acetic acid (Merck, Germany) to prepare a concentrated chitosan solution.

2. The previously prepared Fe_3O_4 nanoparticles were mixed with papaya extract at a 1:1 (w/v) ratio using a magnetic mixer (IKA, Germany) to achieve a homogeneous distribution of the extract on the particle surface.

3. Chitosan solution was added to the previous mixture at different ratios (5%, 10%, 15%), with continuous magnetic stirring at 50°C for one hour to ensure complete homogeneity of the components.

4. After preparation, the product was separated using a strong neodymium magnet and washed several times with distilled water and ethanol to remove excess chitosan and plant extracts.

5. Finally, the product was dried in an electric oven (Memmert, Germany) at 60°C for 12 hours to obtain the final modified Fe_3O_4 powder.

Figure (2) General form of the system used

3- Results and discussion

3-1X-ray diffraction(XRD)

Fe_3O_4 XRD X-ray diffraction results showed a distinct crystalline pattern that reflects the uniform crystal nature of the prepared material. Six main diffraction peaks appeared at 2θ angles (30.50°, 35.90°, 43.50°, 53.90°, 57.40°, 63.00°) Crystalline (220), (311), (400), (422), (511), and (440) respectively, all of which are compatible with the reverse cube of magnetic iron oxide. Fe_3O_4. FWHM was between 0.72° and 0.80°, and the inter-distance (D-Spacing) ranged between 2.929 Å and 1.474 Å, while the sizes of crystals calculated by an equation ranged Shearer is between 111.3 and 124.2 nm, indicating the formation of relatively good crystalline nanoparticles[1]

The structural properties of iron oxide nanoparticles were studied.(Fe_3O_4) using X-ray diffraction (XRD) technology to identify crystalline phases, verify phase purity, and measure crystal size and the effect of various additives on it. The study included three groups of samples: Fe_3O_4 pure, Fe_3O_4 formulated with aqueous papaya extract with chitosan, and Fe_3O_4 formulated using

alcoholic papaya extract with chitosan.

When aqueous extract with chitosan in the composition Fe_3O_4 additional peaks were observed at angles of 20° and 22.5°, attributed to chitosan and papaya extract, a clear indication of surface biological modification. A gradual increase in the crystal size was also observed Fe_3O_4 with increasing chitosan concentration, for example, at 5% chitosan, the crystalline size ranged between 124.4 and 136.8 nm, while at 10%, it increased to 145.4 nm, and then reached a maximum value at 15% chitosan, reaching 152.7 nm. This increase in crystalline size is attributed to chitosan's role in promoting crystal growth by reducing defects on the particle surfaces. The stability ofd-spacing and clarity of the peaks indicate that the introduction of the extract did not negatively affect the synthesis Fe_3O_4 rather, it contributed to improving structural regularity.[7]. These results are clearly shown in Figure (3) and Table (1).

Table (1) X-ray diffraction results in the aqueous extract case

(%)	2θ (°)	FWHM (°)	d-spacing (Å)	Crystallite Size (nm)	Miller Index	المادة
Fe3o4%	30.5	0.74	2.929	111.3	(220)	Fe_3O_4
	35.9	0.72	2.499	116.0	(311)	Fe_3O_4
	43.5	0.75	2.079	114.0	(400)	Fe_3O_4
	53.9	0.8	1.7	111.4	(422)	Fe_3O_4
	57.4	0.77	1.604	117.6	(511)	Fe_3O_4
	63.0	0.75	1.474	124.2	(440)	Fe_3O_4
10%	20.0	1.2	4.43	7.5		Chitosan
	22.5	1.1	3.95	8.3		Papaya Extract
	30.2	0.61	2.957	134.9	(111)	Fe_3O_4
	35.5	0.63	2.527	132.4	(220)	Fe_3O_4
	43.2	0.6	2.092	142.4	(311)	Fe_3O_4
	53.5	0.62	1.711	143.5	(400)	Fe_3O_4
	57.4	0.66	1.604	137.2	(422)	Fe_3O_4
	62.8	0.64	1.478	145.4	(511)	Fe_3O_4

(%)	2θ (°)	FWHM (°)	d-spacing (Å)	Crystallite Size (nm)	Miller Index	المادة
15%	20.0	1.2	4.43	7.5		Chitosan
	22.5	1.1	3.95	8.3		Papaya Extract
	30.3	0.58	2.947	141.9	(111)	Fe_3O_4
	35.6	0.6	2.52	139.1	(220)	Fe_3O_4
	43.3	0.57	2.088	150.0	(311)	Fe_3O_4
	53.6	0.59	1.708	150.9	(400)	Fe_3O_4
	57.5	0.63	1.601	143.8	(422)	Fe_3O_4
	62.9	0.61	1.476	152.7	(511)	Fe_3O_4
5%	20.0	1.2	4.43	7.5		Chitosan
	22.5	1.1	3.95	8.3		Papaya Extract
	30.0	0.65	2.976	126.5	(111)	Fe_3O_4
	35.3	0.67	2.541	124.4	(220)	Fe_3O_4
	43.1	0.63	2.097	135.6	(311)	Fe_3O_4
	53.4	0.66	1.714	134.7	(400)	Fe_3O_4
	57.2	0.69	1.609	131.1	(422)	Fe_3O_4
	62.7	0.68	1.481	136.8	(511)	Fe_3O_4

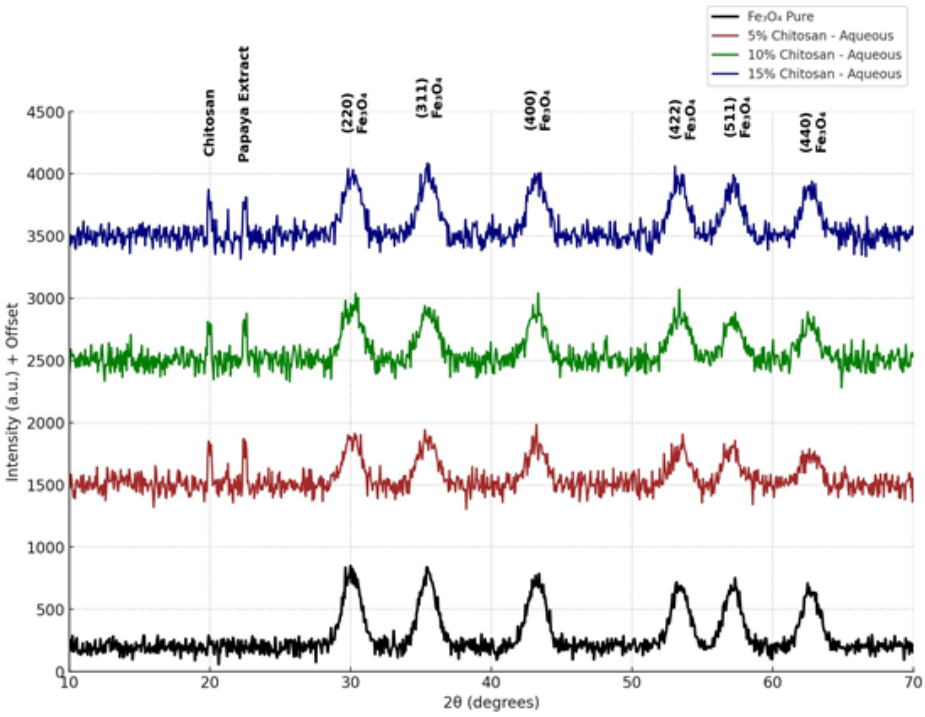

Figure (3) X-ray diffraction pattern of the aqueous extract.

However, when using the alcoholic papaya extract with chitosan, a different behavior was observed. Although the same characteristic peaks appeared for Fe_3O_4 then the FWHM was higher, which was reflected in a decrease in the calculated crystal size compared to the aqueous state. At 5% chitosan, the crystal size was around 120.3 nm, and it gradually decreased to 100.4 nm at 15% chitosan. This decrease in crystal size suggests that the active compounds in the alcoholic extract (such as phenols) partially limited crystal growth by binding to the surfaces of the growing crystals, which led to a restriction in the diffusion of the crystal edges. The higher FWHM values in these samples (between 0.73°–0.88°) compared to the aqueous state reinforces this interpretation. Despite this decrease, the structural regularity remained preserved, as indicated by the symmetry of the peaks [8]. These data are shown in Figure (4) and Table (2).

Table (2) X-ray diffraction results in the case of alcoholic extract

النسبة (%)	(°) 2θ	FWHM (°)	d-spacing (Å)	Crystallite Size (nm)	Miller Index	المادة
النقي Fe_3O_4	30.5	0.8	2.929	105.2	(220)	Fe_3O_4
	35.9	0.82	2.499	104.0	(311)	Fe_3O_4
	43.5	0.85	2.079	102.7	(400)	Fe_3O_4
	53.9	0.88	1.7	101.4	(422)	Fe_3O_4
	57.4	0.91	1.604	99.8	(511)	Fe_3O_4
	63.0	0.94	1.474	98.3	(440)	Fe_3O_4
0%	30.5	0.74	2.929	111.3	(220)	Fe_3O_4
	35.9	0.72	2.499	116.0	(311)	Fe_3O_4
	43.5	0.75	2.079	114.0	(400)	Fe_3O_4
	53.9	0.8	1.7	111.4	(422)	Fe_3O_4
	57.4	0.77	1.604	117.6	(511)	Fe_3O_4
	63.0	0.75	1.474	124.2	(440)	Fe_3O_4

النسبة (%)	2θ (°)	FWHM (°)	d-spacing (Å)	Crystallite Size (nm)	Miller Index	المادة
5%	62.7	0.68	1.481	136.8	(511)	Fe_3O_4
	57.2	0.69	1.609	131.1	(422)	Fe_3O_4
	43.1	0.63	2.097	135.6	(311)	Fe_3O_4
	53.4	0.66	1.714	134.7	(400)	Fe_3O_4
	30.0	0.65	2.976	126.5	(111)	Fe_3O_4
	22.5	1.1	3.95	8.3		Papaya Extract
	20.0	1.2	4.43	7.5		Chitosan
	35.3	0.67	2.541	124.4	(220)	Fe_3O_4
10%	62.8	0.64	1.478	145.4	(511)	Fe_3O_4
	57.4	0.66	1.604	137.2	(422)	Fe_3O_4
	43.2	0.6	2.092	142.4	(311)	Fe_3O_4
	53.5	0.62	1.711	143.5	(400)	Fe_3O_4
	30.2	0.61	2.957	134.9	(111)	Fe_3O_4
	22.5	1.1	3.95	8.3		Papaya Extract
	20.0	1.2	4.43	7.5		Chitosan
	35.5	0.63	2.527	132.4	(220)	Fe_3O_4
15%	57.5	0.63	1.601	143.8	(422)	Fe_3O_4
	20.0	1.2	4.43	7.5		Chitosan
	22.5	1.1	3.95	8.3		Papaya Extract
	30.3	0.58	2.947	141.9	(111)	Fe_3O_4
	35.6	0.6	2.52	139.1	(220)	Fe_3O_4
	43.3	0.57	2.088	150.0	(311)	Fe_3O_4
	53.6	0.59	1.708	150.9	(400)	Fe_3O_4
	62.9	0.61	1.476	152.7	(511)	Fe_3O_4

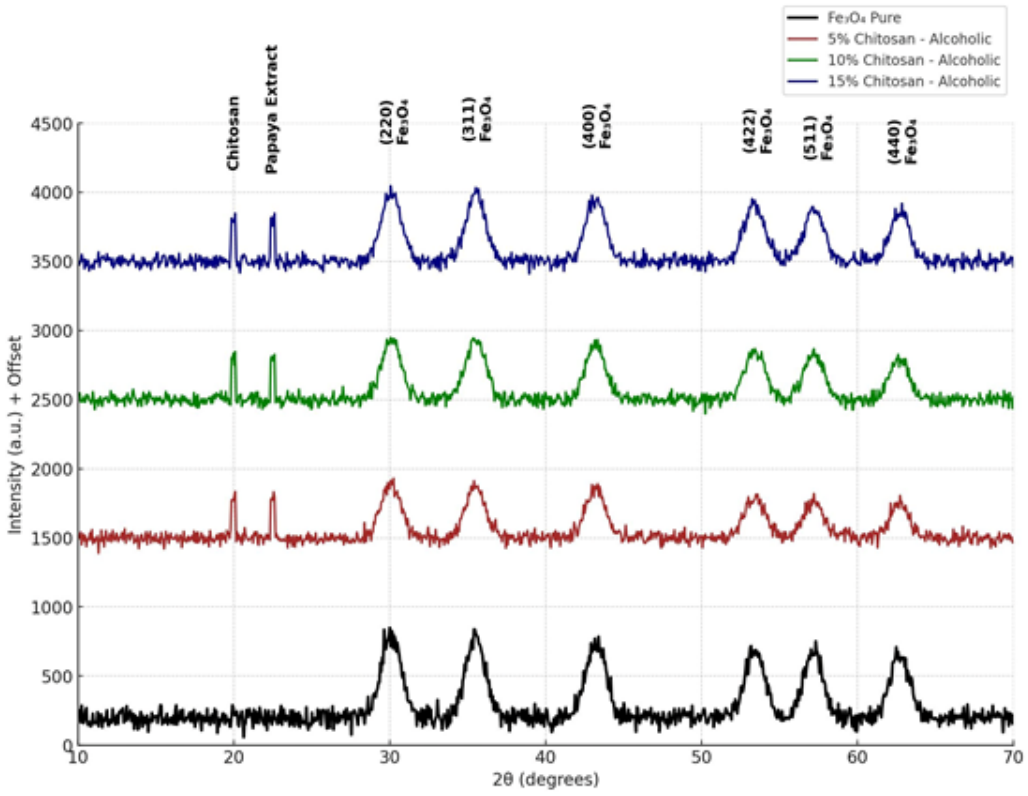

Figure (4) X-ray diffraction pattern of the alcoholic extract

Comparing the three cases, it is noted that the pure sample exhibited excellent crystalline regularity with a medium crystal size. Meanwhile, the aqueous extract with chitosan significantly enhanced crystal growth, resulting in the highest recorded crystal size. In contrast, the alcoholic extract maintained crystal regularity but slightly inhibited growth, resulting in more stable particles with a lower crystal size, which is desirable for some applications requiring a fine-scale distribution of nanoparticles. Therefore, the efficiency of the system depends on the nature of the final application. If applications require larger crystals (such as in magnetic fields), the aqueous sample may be preferred, while for biological or catalytic applications that require smaller nanoparticle sizes and higher stability, the alcoholic system is a better choice.

2scanning electron microscope (SEM)

SEM images of pure Fe$_3$O$_4$ showed

quasi-spherical particles with an average size of 97.5 nm and a standard deviation of 2.8 nm. The sample prepared with the aqueous extract retained its nearly spherical shape with some surface agglomeration resulting from the encapsulation of chitosan and biocomposites.

Scanning electron microscope analysis results showed(SEM) Significant difference in grain size values between the three samples: Fe_3O_4 pure, aqueous, and alcoholic extract-prepared samples coated with varying proportions of chitosan were analyzed. This analysis provides an accurate picture of the effect of both the plant extract and the nature of the biopolymer (chitosan) on the growth and distribution of nanoparticles.

When papaya water extract to Fe_3O_4 then, the resulting particles were coated with chitosan polymer at ratios of 5%, 10%, and 15%. A gradual decrease in the particle size was observed from86.0 nm to 80.0 nm and then to 74.0 nm respectivelyAs shown in Table (3) and Figure (5)This decrease is attributed to the effect of the amorphous surface layer formed by chitosan on the particles, which suppresses natural grain growth and prevents the crystals from coalescing together.[9]. The presence of active compounds in the aqueous extract also contributed to some structural stabilization of the particles, but with relatively limited effectiveness due to the less chemically active nature of the aqueous extract compared to the alcoholic one.

Table (3) Scanning electron microscope results in the aqueous extract condition.

Chitosan percentage	grain size(nm)	standard deviation
Pure Fe3O4	97.5	2.8
5%	86.0	3.3
10%	80.0	2.1
15%	74.0	2.6

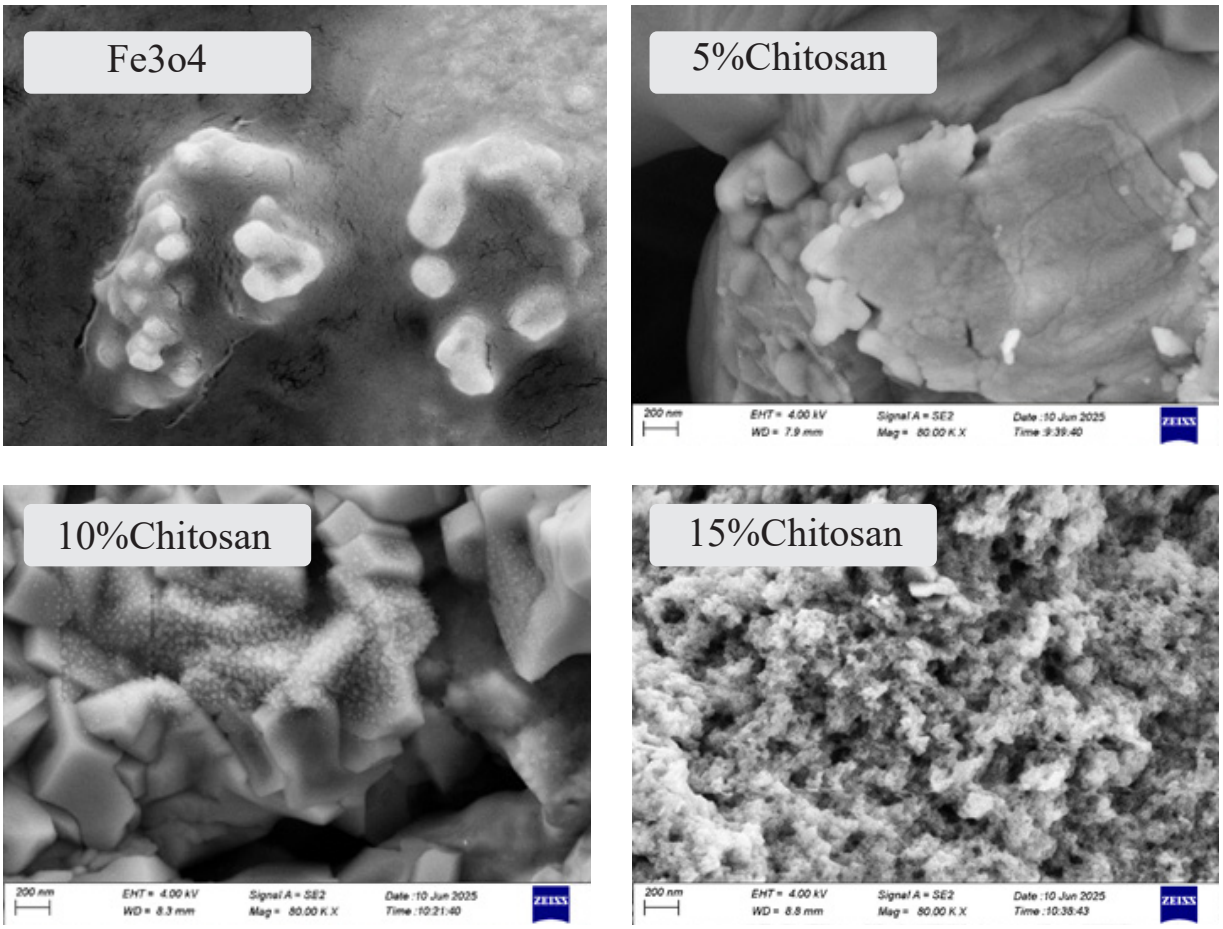

Figure (5) Microscopic images of samples in the aqueous extract state and with different percentages of catiosan additions.

The Fe_3O_4 sample prepared with alcoholic extract showed a smaller crystal size of 83 nm with a standard deviation of 2.8 nm, with a more uniform distribution and smoother surface texture due to the effect of the alcoholic extract and the chitosan layer.

In the case of the alcoholic papaya extract, the results were more evident in terms of stabilization effectiveness and control of particle size. The particle size decreased from77.0 nm at 5% chitosan to 72.0 nm at 10%, then to 67.0 nm at 15%As shown in Table (4) and Figure (6)This decrease is an indication of the effectiveness of the alcoholic extract in controlling particle growth, due to its higher concentration

of phenolic and terpenic compounds with high inhibitory activity. These compounds work to trap growing particles and prevent them from coalescing into large aggregates, leading to the formation of finer and more uniform nanoparticles..

The electrostatic bond between the positive amine groups in chitosan and the surface components of the particles helped create an outer layer that prevents merging between neighboring particles, which explains the gradual decrease in particle size with the increase in the proportion of chitosan in both types of extracts.[10]

Comparing the two types, it can be said that the alcoholic extract demonstrated a better ability to adjust the particle size and control the regularity of the particles, which reinforces the hypothesis that the nature of the alcohol-extracted compounds plays an important role in directing crystal growth during the preparation process. The apparent consistency in the changes within the alcoholic group compared to the aqueous group also indicates greater stability under reaction conditions and better control over the structural mechanics of the particles..

Table (4) Scanning electron microscope results in the extracted state.alcoholic

Chitosan percentage	grain size(nm)	standard deviation
Pure Fe3o4	83	2.8
5%	77.0	2.3
10%	72.0	2.17
15%	67.0	1.9

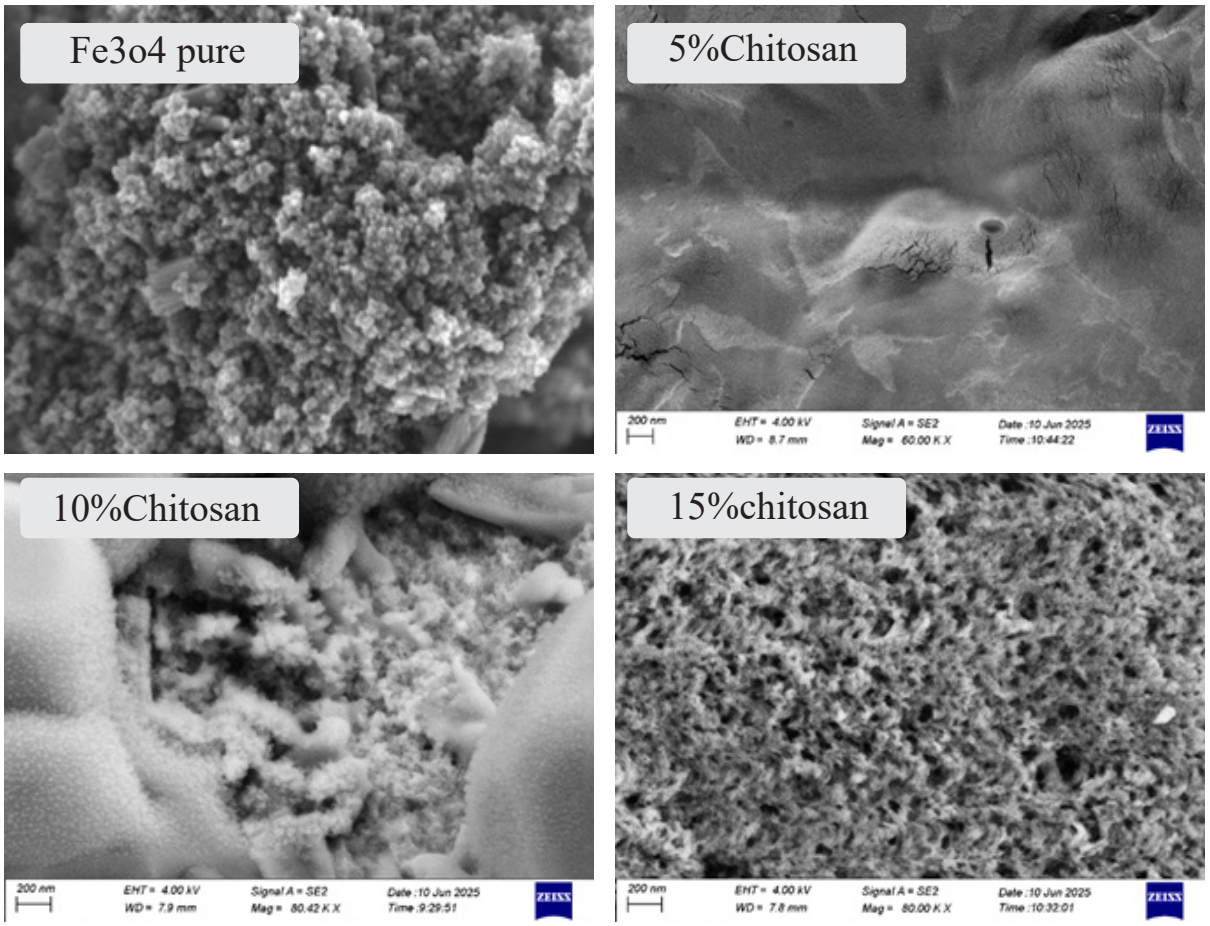

Figure (6) Microscopic images of samples in the extracted state. alcoholicWith different additions of chitosan

4 Transmission electron microscopeTEM (Transmission Electron Microscopy)

TEM images of pure Fe_3O_4 particles showed an irregular spherical shape, with an average diameter of 14.3 nm, and a total number of 83 observed particles.

Analysis was performed.TEM to determine the molecular shape and measure the average diameters of nanoparticles prepared in three main states: Fe_3O_4 pure, Fe_3O_4 encapsulated with aqueous papaya extract, chitosan, and Fe_3O_4 encapsulated with alcoholic extract and chitosan. Images and data analysis revealed clear changes in molecular size and shape depending on the nature of the treatment and the chemical composition of the nanocomposite.

In the samples in which the aqueous papaya extract was used with chitosan, a gradual decrease in the diameter of the particles was observed.13.5 nm at 5% chitosan to 10.9 nm at 15%As

shown in Table (5)The molecular shape also gradually changed from irregular spherical to semi-spherical, indicating that the aqueous layer of the plant extract with chitosan restricted the partial growth of the particles without creating an ideal encapsulation system, which explains the relatively irregular shapes remaining.[11] It also indicates the presence of simple clumps that may have resulted from poor distribution within the aqueous medium.

Table (5) Microscope results electronic The windowIn aqueous extract

Chitosan percentage	molecular shape	Particle diameter(nm)	Number of observed particles
Pure Fe3o4	Irregular spherical	14.3	83
5%	irregular spherical	13.5	90
10%	irregular spherical	12.2	98
15%	semi-spherical	10.9	109

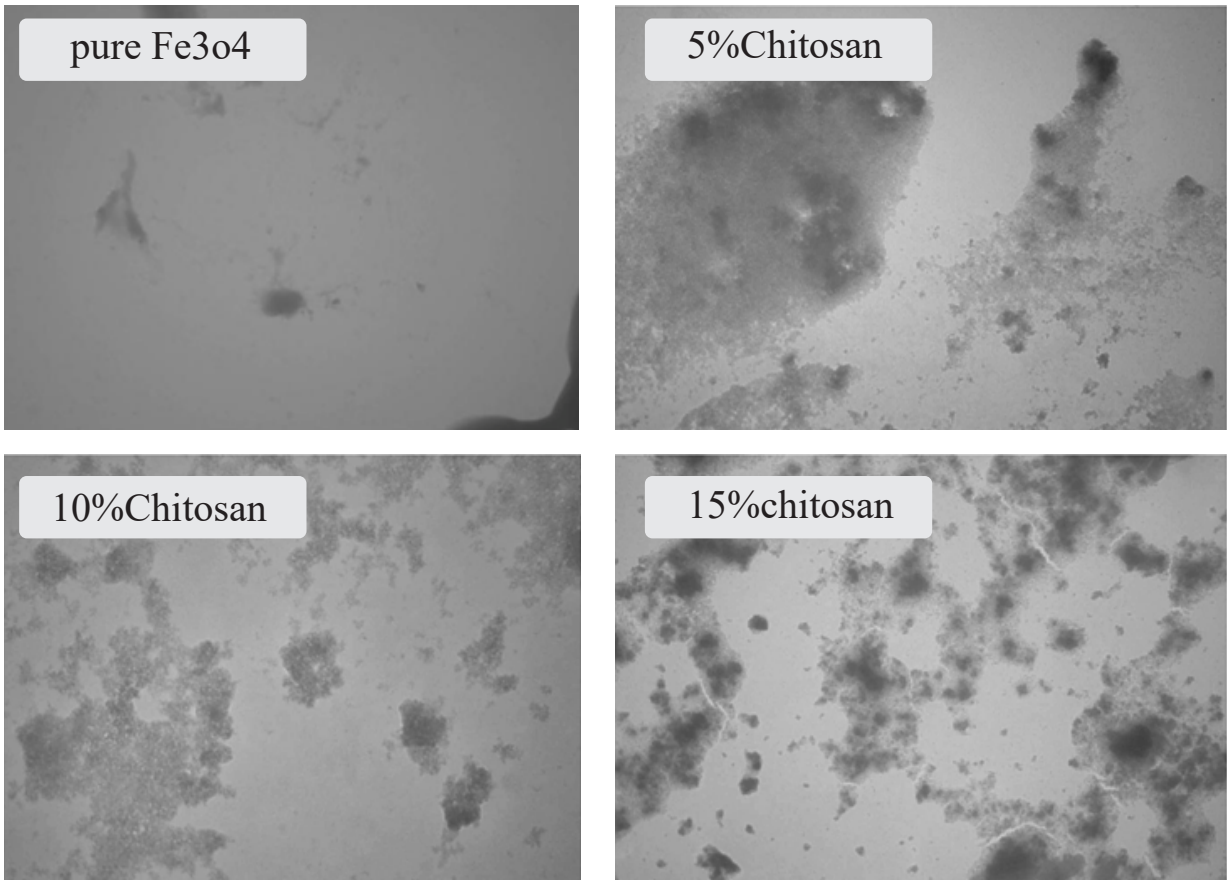

Figure (7) Microscopic images of samples
in the aqueous extract state and with different percentages of chitosan added.

TEM images of pure Fe_3O_4 revealed a nearly regular semispherical shape, with an average diameter of 14.7 nm, and an observed number of 129 particles.

In contrast, when using alcoholic papaya extract with chitosan, more consistent and disciplined results were achieved in terms of both size and shape. The particles exhibited asemi Regularly spherical in proportions of 5% and 10% chitosan, gradually transforming into sphericalregularAt 15%. The diameter also decreased from13.0 nm to 10.1 nm. This behavior reflects the effectiveness of alcohol-extracted compounds, such as phenols and terpenes, in controlling particle growth and preventing agglomeration, enabling the formation of more stable and homogeneous nanoshells[12]. The morphological regularity is attributed to the stronger interaction between chitosan and the active compounds in the alcoholic extract, which provides a smooth, tight encapsulation that restricts granular growth more precisely than the aqueous extract.

Overall, it can be said that the addition of chitosan to the magnetic particles effectively contributed to reducing the particle diameters and improving their uniformity, and that the alcoholic extract was more efficient than the aqueous extract in directing this effect. The higher number of particles observed in the alcoholic samples compared to the aqueous ones indicates better distribution and greater stability of the particles under the microscope..

Table (6) Microscope results electronic scanner in mint condition alcoholic

Chitosan percentage	molecular shape	Particle diameter(nm)	Number of observed particles
Pure Fe3o4	Semispherical	14.7	129
5%	semispherical	13.0	117
10%	semiregular	11.8	124
15%	regular spherical	10.1	111

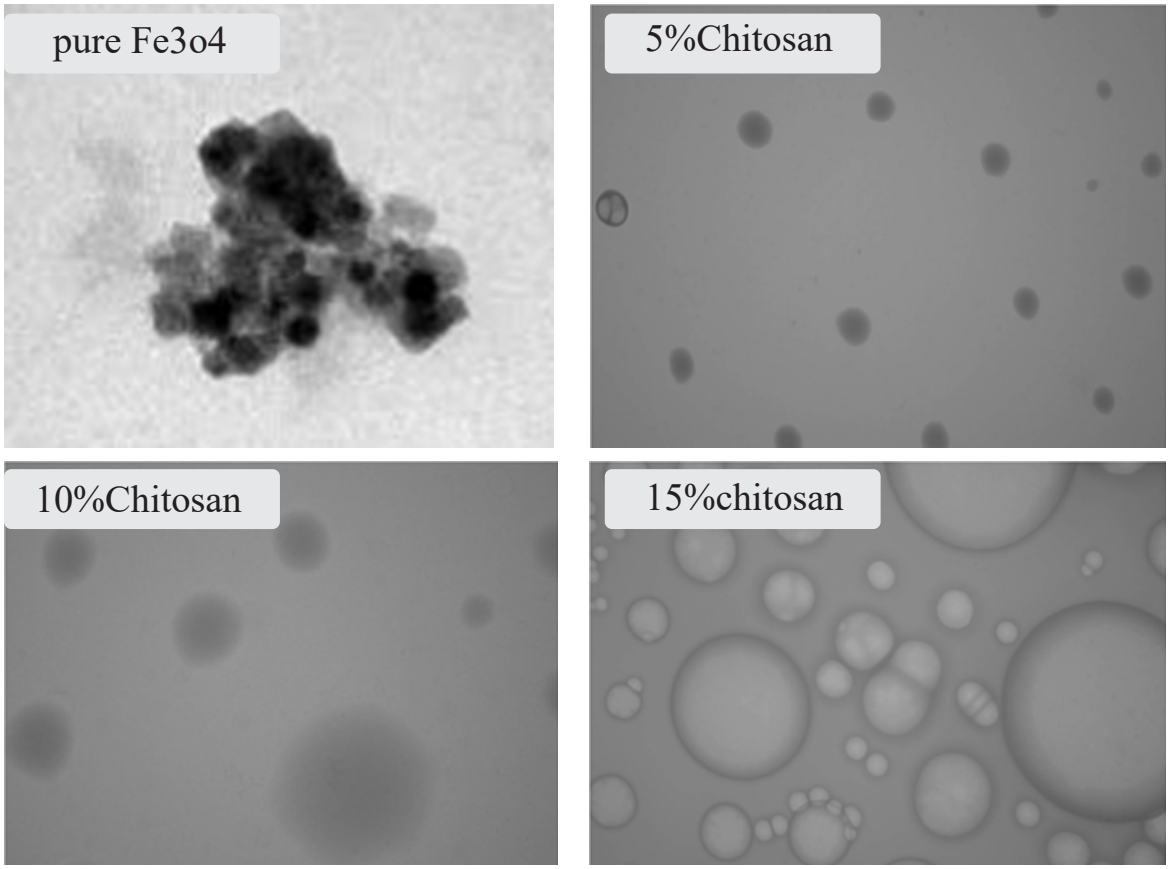

Figure (8) Microscopic images of samples in the extracted state.alcoholic With different additions of chitosan

3-4 Vibration MagnetometerVSM

The VSM results of the pure Fe_3O_4 sample showed strong magnetic properties, with a magnetic saturation (Ms) of about 68.5 emu/g, a magnetic residual (Mr) of 6.1 emu/g, and a magnetic retention strength (Hc) of 112 Oe, indicating a distinct magnetic behavior with moderate magnetic residual retention.

Magnetic results obtained using the technique showed thatVSM showed a clear change in the magnetic properties of nanoparticles depending on the sample type and composition, starting with Fe_3O_4 With papaya extracts (aqueous and alcoholic) and encapsulated with different proportions of chitosan.

When aqueous papaya extract is introduced into the formula Fe_3O_4 with the particles coated with varying proportions of chitosan (5%, 10%, 15%), a gradual decrease inMs, where values decreased from 61.3 emu/g to 55.8 emu/g and then to 49.7 emu/g,

which confirms that the introduction of non-magnetic materials such as chitosan and bio-based compounds in the aqueous extract reduces the relative concentration of magnetic material within the system, thus reducing the overall ability of the particles to saturate under the magnetic field. Mr values also witnessed a gradual decrease from 5.4 to 4.7 and then to 3.9 emu/g,As in Figure (9)This indicates that the material became less able to retain its magnetism after the field was removed, due to the insulating effect of the bio-coating layers.[13,14]. As for the coercive field Hc, a gradual increase was observed from 125 to 132 and then to 140 Oe, reflecting that the particles became more resistant to changing their magnetic orientation due to surface barriers and interferences caused by the chitosan layer and water compounds, which is an expected magnetic behavior in systems with dense packing.

Table (7) Results VSM for samples in aqueous extract state

Chitosan percentage	Ms (emu/g)	Mr. (emu/g)	Hc (Oe)
Pure Fe3o4	68.5	6.1	112
5%	61.3	5.4	125
10%	55.8	4.7	132
15%	49.7	3.9	140

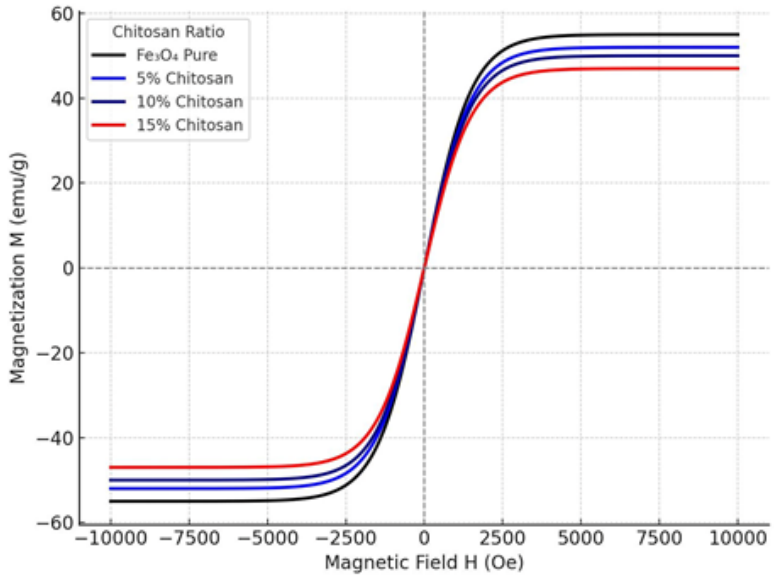

Figure (10) a plan VSM for samples in aqueous extract state

The alcohol-prepared sample showed a slight decrease in magnetic saturation, with Ms of about 66.1 emu/g, Mr of 5.9 emu/g and Hc of 113 Oe, indicating that the sample retained good magnetic properties with limited influence of the alcoholic extract on the magnetic behavior.

When using alcoholic papaya extract instead of aqueous, the samples showed better and more stable magnetic properties. In the 5% chitosan sample,The Ms value was 63.2 emu/g, which is higher than the corresponding value in the aqueous sample. Ms continued to gradually decrease with increasing chitosan content, reaching 58.5 emu/g at 10% and then 52.4 emu/g at 15%. However, these values remained higher in all cases than their counterparts in the aqueous group. This indicates that the alcoholic extract contains active compounds that have a less isolating effect on the nanoparticles, contributing to a greater preservation of magnetic performance [15,16]. The alcoholic samples were also observed to have superior Mr values, starting at 5.8 emu/g and gradually decreasing to 5.1 and then 4.2 emu/g, while maintaining a clear difference compared to the aqueous sample. The coercive field, Hc, maintained lower values than the aqueous sample, being 115 Oe at 5% and then increasing to 121 and 130 Oe, respectively.As in Table (8) and Figure (11)This indicates a more flexible and rapid magnetic response in alcohol particles, a desirable property in biological applications that require instantaneous and dynamic response under the influence of external magnetic fields..

The superiority of the alcohol system in magnetic properties is due to the fact that alcohol-extracted biomolecules are more effective at forming thin, uniform shells around the particles, ensuring better nanodispersion and reducing agglomeration and surface interference that hinders magnetic interaction. Conversely, the aqueous system often results in the formation of thicker, more heterogeneous shells, which weakens the overall magnetic effect and increases resistance to moment rearrangement. Therefore, it can be said that encapsulation Fe_3O_4 alcoholic extract with chitosan provides an ideal balance between magnetic performance and particle stability, making it the best choice for biological applications that rely on magnetic field control.

Table (8) Results VSM For samples in alcoholic extract condition

Chitosan percentage	Ms (emu/g)	Mr. (emu/g)	Hc (Oe)
Pure Fe3o4	66.1	5.9	113
5%	63.2	5.8	115
10%	58.5	5.1	121
15%	52.4	4.2	130

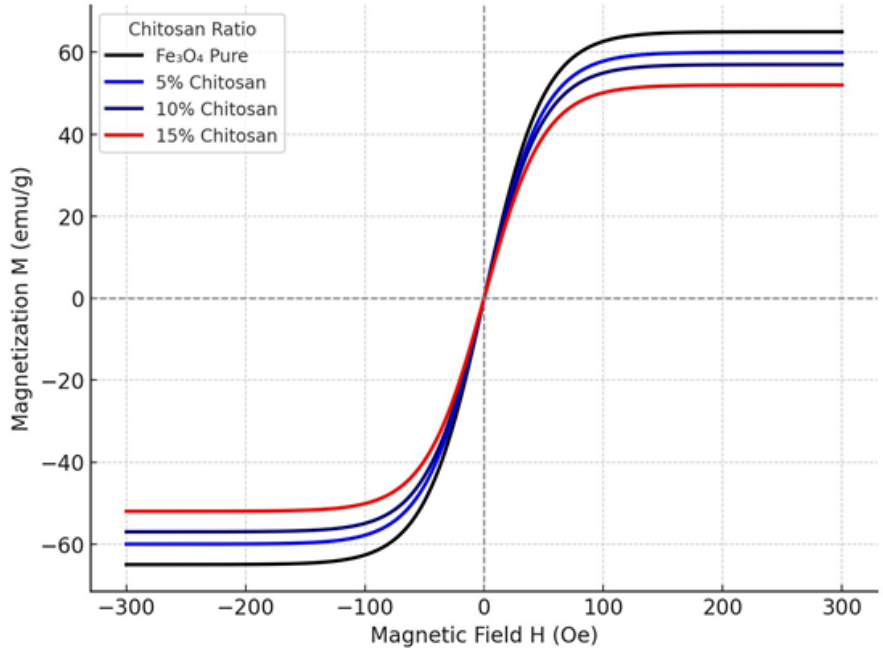

Figure (11) results VSM for samples in the extracted statealcoholic

Conclusions

The study shows that the nature of the plant extract plays a crucial role in directing the structural and magnetic properties of the particles.Fe_3O_4 nanoparticles. The use of the alcoholic extract reduced the crystal and grain size and enhanced particle regularity. It also maintained a high magnetic saturation compared to the aqueous extract, making it more efficient for bio-applications. In contrast, the aqueous extract promoted crystal growth and increased size without adversely affecting the structure.

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