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Green synthesis and characterization of iron oxide nanoparticles using *Coriandrum sativum* L. leaf extract

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Green nanoparticle synthesis is a promising, eco-friendly and safe approach. In the current study, Iron oxide nanoparticles (FeONPs) were synthesized using aqueous leaf extract of *Coriandrum sativum* L. Further, the characterization of synthesized FeONPs was performed using ultraviolet-visible spectroscopy, transmission electron microscopy (TEM), dynamic light scattering (DLS), vibrating sample magnetometer (VSM) and differential scanning colorimetry (DSC). The surface plasmon resonance effect confirmed the synthesis of FeONPs. Dynamic light scattering (DLS) revealed mean particle size of FeONPs around 163.5 and polydispersity index 0.091 with a zeta potential of −13.8 mV. Differential scanning colorimetry (DSC) exhibited an endothermic peak at 176.91°C. Vibrating sample magnetometer (VSM) analysis showed superparamagnetic properties of iron nanoparticles with a magnetization value of 3.483 emu/g and the results indicated superparamagnetic behavior of prepared iron nanoparticles at room temperature, thus highlighting their potential as magnetically targeted drug delivery system. This biosynthetic method has been proven to be cost-effective, environment friendly and promising for use in biomedical sciences.

Keyword: *Coriandrum sativum* L., Iron Oxide nanoparticle, Superparamagnetic

Nanotechnology is a rapidly expanding field with various application in biological, medicine, and technology. Nanotechnology has advanced in the field of nanoscience over the last 20 years. The synthesizing of nanoparticles (NPs) of different shapes and sizes, as well as their potential applications, are the emphasis of nanotechnology[1]. Most experts believe that metal oxide NPs are quite safe for humans and the environment. Metal oxides are commonly used in a variety of fields including environmental research, electrochemistry, and magnetic biology[2]. Iron oxide (FeO) is notable for its biocompatibility and magnetic characteristics and is one of the better metallic NPs for the treatment of certain diseases and infections. Iron oxide nanoparticles (FeONPs) have a wide range of applications, including catalysts, heavy metal adsorption, dyes, and antibiotic degradation[3]. However, the physical and chemical processes for synthesizing nanoparticles result in clear and distinct nanoparticles, these nanoparticles may not be environment-friendly, and they are highly expensive[4]. Moreover, using the above-mentioned processes to create agglomerates could lead to lower reactivity and stability in these nanoparticles[5]. In recent years, phytomediated synthesis of nanomaterials has gained popularity since it has various advantages such as being clean, fast, eco-friendly, and non-toxic, and the plant material itself functions as a capping agent[6]. The plant's biological components are integrated with the NPs, which maintains stability and improves shape[7]. Recently, many studies have been conducted for the green synthesis of iron-based nanoparticles from different plant parts such as *Persea americana* rind, *Cynometra ramiflora* fruit extract, *Avicennia marina* flower extract, *Punica granatum* seeds extract etc. for the degradation of different textile dyes[8-11].

The current study attempted to produce iron oxide nanoparticle using *Coriandrum sativum* L. leaf extract. Aqueous ferrous sulphate reactions with *C. sativum* L. leaf extract to produce FeONPs, which are highly stable. The rate of nanoparticle synthesis is extremely fast, which allows the use of crop residues in the synthesis of iron nanoparticles using environmentally benign and more secure methods.

Material and Methods

Materials

Analytical grade Ferrous sulfate heptahydrate was purchased from Himedia Pvt Laboratories (Mumbai) India. The freshly *C. sativum* L. leaves were procured

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from a local market. Further, the sample was authenticated by Dr. Munruchi Kaur, Department of Botany, Punjabi University, Patiala (Punjab), India (account No.: 2021–673).

Preparation of aqueous leaf extract

Fresh *C. sativum* L. leaves were collected and washed with tap water and deionized water. The aqueous extract of leaves was prepared by combining 10 g of plant leaf (cut into small pieces) with 100 mL of deionized water in a 250 mL beaker. After heating the solution to 60°C for 1 h. Then it was cooled and filtered using Whatman No. 1 filter paper. To get a clear solution, the filtrate was centrifuged. A freeze dryer was used to dry this clear extract. This dried powder was passed through 60-mesh sieve and the sample was stored at room temperature in an airtight container for further studies[12].

Biosynthesis of iron oxide nanoparticles

Nanoparticles of iron oxide (FeONPs) have been prepared by addition of *C. sativum* leaf extract dropwise to 0.01 (mM) $FeSO_4$ in a 100 mL conical flask with constant agitation speed at 1000 rpm. The reaction mixture was agitated for 15 min at 30°C using a magnetic stirrer[13]. The prepared iron oxide nanoparticles (FeONPs) then separated at 15000 rpm for 20 min by centrifugation. The supernatant was discarded and the pellet was washed by triple distilled water and centrifuged several times to purify it. The iron oxide nanoparticles were freeze-dried for 24 h at −78°C with a pressure of 10 Pa. The black pellet was dried and preserved for future research.

Characterization of synthesized FeONPs

A UV-vis spectrophotometer (Shimadzu UV 2450) was used to confirm the synthesis of FeONPs. To determine the size, shape, and elemental composition of FeONPs were using TEM (JEM-1200 Ex, Joel, Japan). It was found that Dynamic light scattering (DLS) was able to estimate the average size, zeta potential and poly dispersity index (PDI) of the synthesized FeONPs (Malvern Instruments Ltd., Malvern, UK) used water as a solvent. The magnetic property of the synthesized FeONPs was determined by drying the nanoparticles to a fine powder. The powdered material was analyzed on a Microsense VSM at the room temperature. Furthermore, the thermal behaviour of a surface capped FeONPs was investigation with DSC (Melter Toledo, DSC 3 star system).

Results and Discussion

Biological synthesis and characterization of FeONPs

FeONPs were prepared using a green approach with *C. sativum* leaf extract in this study. Generally, the leaves of *C. sativum* are high in polyphenol derivatives. The addition of *C. sativum* leaf extract with ferrous sulphate immediate changed in the colour of reaction mixture from brownish to black colour. This colour change suggested a reduction of Fe^{+2} ions to zero-valent iron (Fig. 1). The reaction mixture's colour shift resulted in the activation of surface plasmon vibrations from NPs. UV-vis spectroscopy was used to monitor the reduction of Fe^{+2} ions in the aqueous extract of *C. sativum* leaf extract.

The formation of iron oxide nanoparticles has indicated by the presence of a strong peak at 225 nm (Fig. 2)[14]. FeONPs synthesized using Musa ornate flower sheath extract[15] and *Azardirachta indica*[16] leaf extract are in good agreement with proceeding study. The reduction of iron oxide nanoparticles by *C. sativum* L. extract was confirmed by the presence of appropriate surface plasmon resonance (SPR) with high band intensities and peaks in the visible spectrum[17].

According to DLS study, the mean particle size of the iron oxide nanoparticles was around 163.5 nM (Fig. 3A) due to the increased interfacial surface area. The Polydispersity Index (PDI) has also used to attain information on the size distribution and homogeneity of nanoformulations. The negative charge of zeta potential value was −13.0 mV[18]. Which proven moderately stable of the iron nanoparticles (Fig. 3B). The zeta potential indicates the stability of nanoformulations, and a negative value indicates that particle aggregation in the continuous phase has decreased[19]. The negative value of iron oxide nanoparticles supports the conjugation of polyphenolic compounds kaempherol, 40-O mequercetin quercetin, 30-O mequercetin, acacetin, vanillic acid, and trans-ferulic acid on the surface of iron oxide nanoparticles[20].

Fig. 1 — (A) *C. sativum* leaf extract; (B) 0.01M ferrous sulphate; and (C) Synthesized iron oxide nanoparticles

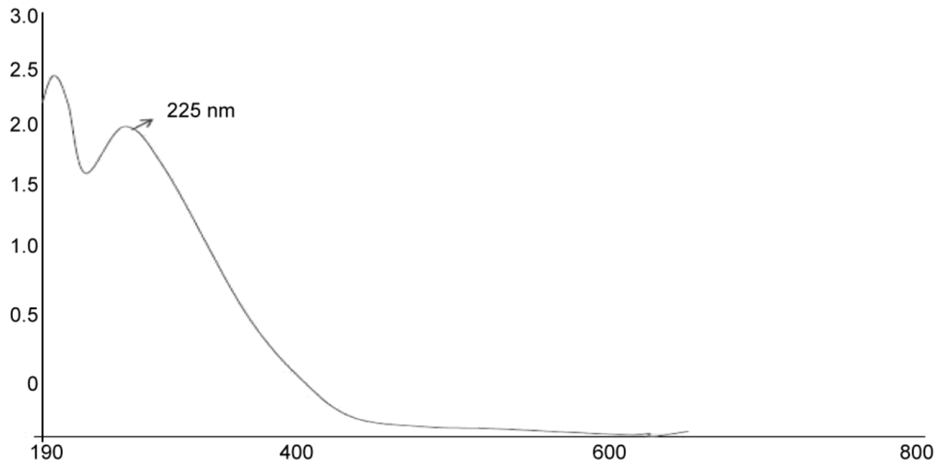

Fig. 2 — UV-vis spectrum image of synthesized iron oxide nanoparticles

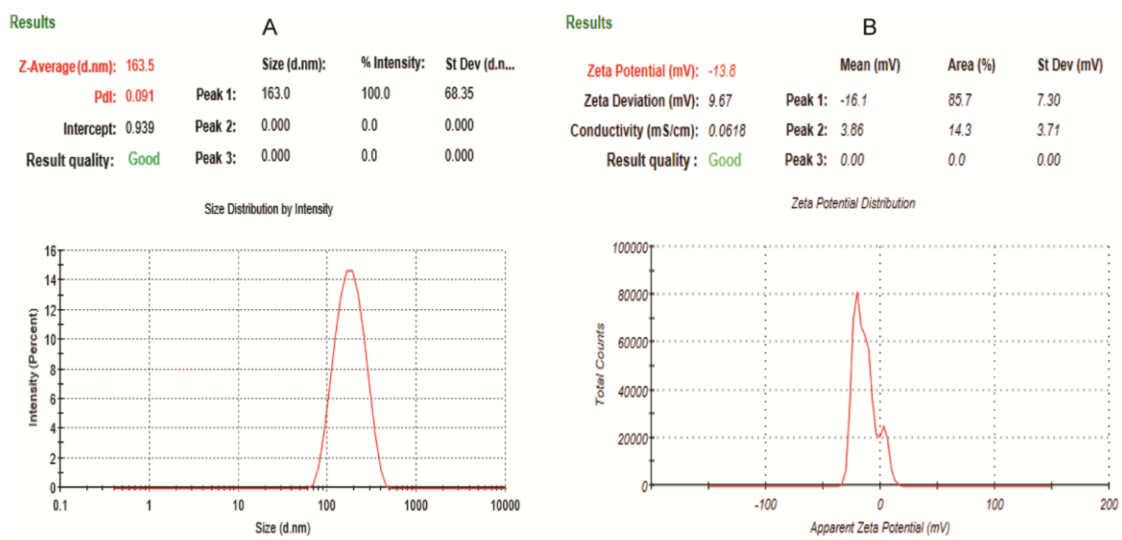

Fig. 3 — (A) Mean particle size; and (B) Zeta potential of optimized iron oxide nanoparticles

The size and surface morphology of prepared iron nanoparticles were examined by TEM. The images revealed nearly spherical and monodisperse nature of nanoparticle with minimum agglomeration (Fig. 4). This indicates the successful formation and stabilization of iron nanoparticles. This indicates that the phytoconstituents of *C. sativum* L leaves act as efficient reducing and capping agent. This was in consonance with earlier findings[21].

The thermal behaviour of green synthesized FeONPs was investigated using differential scanning calorimeter. As shown in Figure 5, single endothermic peak was seen at 176.91°C. This might be due to desorption of water molecules from the surface of iron nanoparticles. Recently, Lakshminarayanan *et al.*, 2021[22], also reported endothermic peak at 180°C. The absence of any other exothermic or endothermic peak clearly indicates thermal stability of green synthesized nanoparticles. Hence, phytoconstituents present in aqueous extract of *C. sativum* L. efficiently reduced and stabilized FeONPs.

A vibrating sample magnetometer (VSM) was used to measure the magnetic properties of prepared iron nanoparticles. Thus, the magnetometry of the formed nanoparticles was measured at room temperature in the -16,000 to 16,000 O_e (Oersted) magnetic field. The saturation magnetization (Ms) of prepared FeONPs was 3.483 emu/g while the remnant magnetization (Mr) was 45.389 emu/g and the coercivity (Ce) value was 62.969G. The disappearance of hysteresis loop in (Fig. 6), revealed the superparamagnetic nature of green synthesized FeONPs. It also indicates the absence of long-range magnetic dipole-dipole interaction among the assemblies of superparamagnetic NPs.

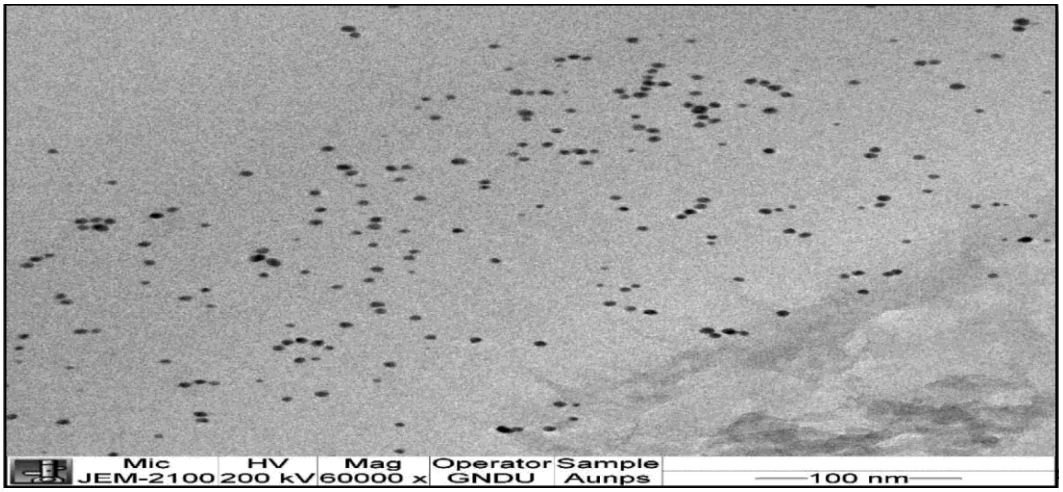

Fig. 4 — Transmission electron micrograph of iron oxide nanoparticles at a magnification of 150000 X

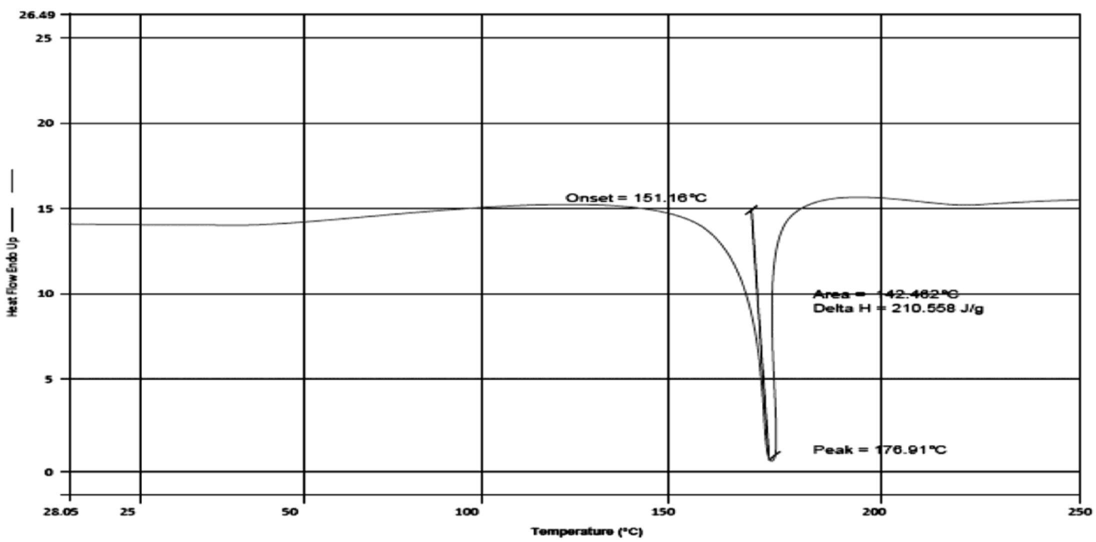

Fig. 5 — DSC curves of iron oxide nanoparticles obtained from aqueous extract of *C. sativum* L.

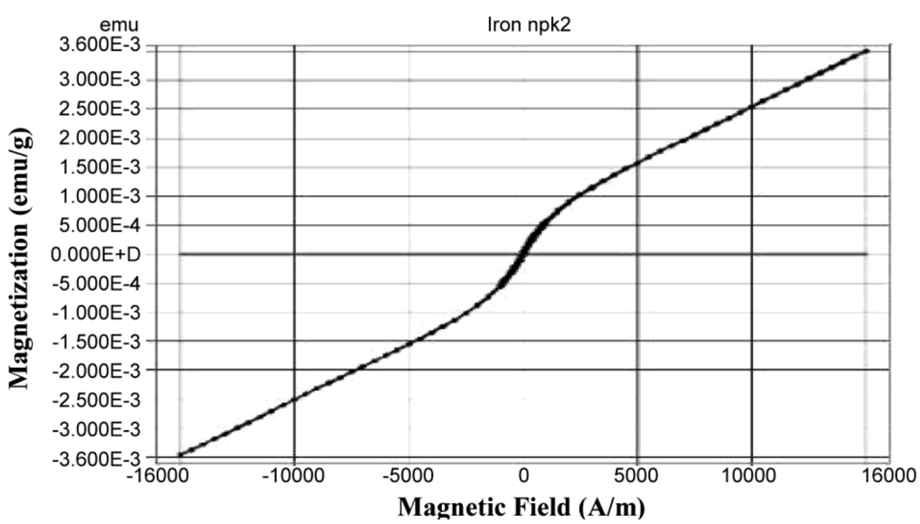

Fig. 6 — Magnetization of green synthesized iron oxide nanoparticles against applied magnetic field

However, the sigmoidal shape of the graph indicates presence of nanostructures with small magnetic fields. The magnetic measurements of the green synthesized FeONPs were similar to the work reported by Mamani *et al*., 2014 and Andrade *et al*., 2020[23,24].

Conclusion

FeONPs was successfully synthesized using a green synthesis technique with *Coriandrum sativum* L. leaf extract. *C. sativum* leaf extracts with strong antioxidant capacity. The polyphenols like quercetin present in leaf extract act as both reducing and capping agents for the nanoparticles thus producing discrete iron nanoparticles. The approach used is safe, sustainable and cost-effective for large-scale production of iron nanoparticles.

Conflict of interest

All authors declare no conflict of interest.

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