Nguyen *et al.*
Journal of Analytical Science and Technology 2022, **13**(1):28
https://doi.org/10.1186/s40543-022-00337-2

Journal of Analytical Science and Technology

RESEARCH ARTICLE

Open Access

Isolation of DNA from *Arthrospira platensis* and whole blood using magnetic nanoparticles (Fe_3O_4@OA and Fe_3O_4@OA@SiO_2)

Lien-Thuong Thi Nguyen[1*], Ngoc-Hanh Thi Le[1], Hanh Kieu Thi Ta[2,3,4] and Khoa Dang Nguyen[1]

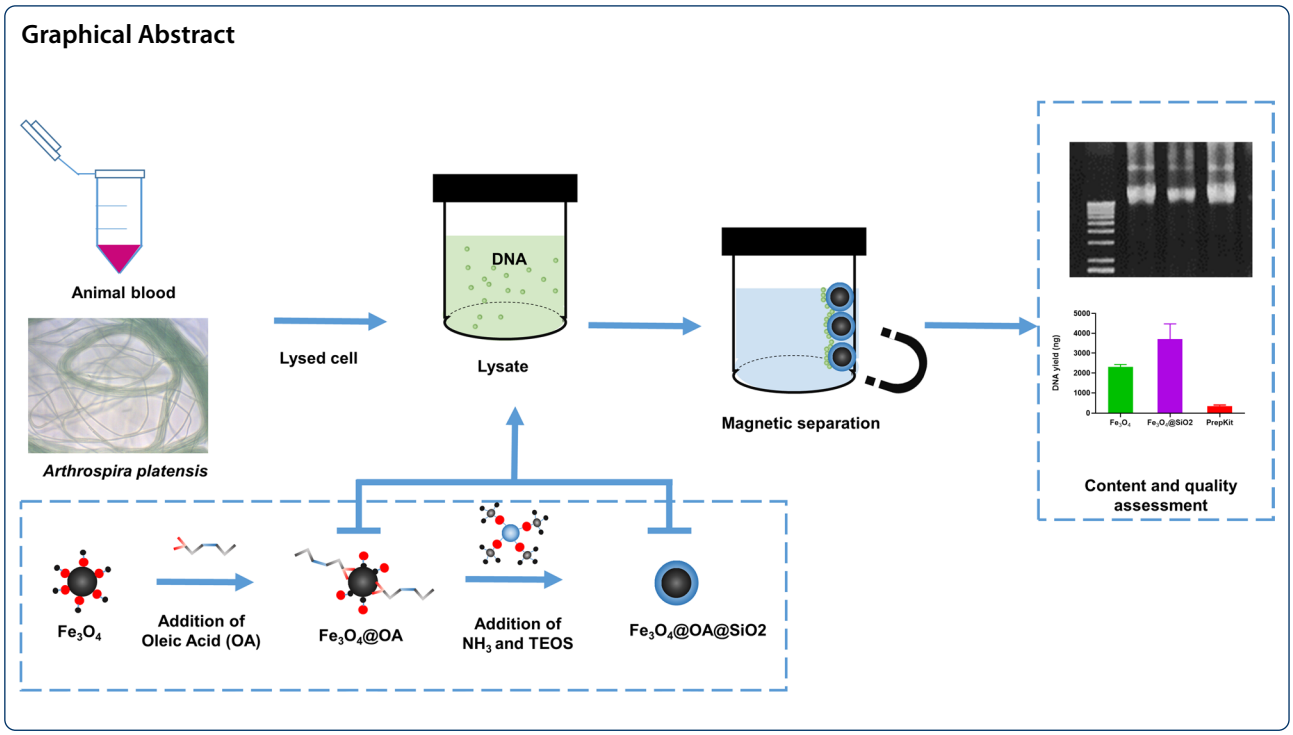
Abstract

Magnetic nanoparticles (MNPs) provide a fast, cost-effective, and organic-free method for DNA isolation. In this paper, we synthesized MNP coated with oleic acid (Fe_3O_4@OA) and silica nanoparticles (Fe_3O_4@OA@SiO_2), characterized the properties of MNP using TEM, VSM, and FTIR, and investigated their efficiency in DNA isolation from cyanobacteria. The yield and quality of isolated DNA were evaluated and compared with those from animal blood and those obtained by the silica column or organic solvents. The results showed the successful preparations of Fe_3O_4@OA and Fe_3O_4@OA@SiO_2 with superparamagnetic behaviors and a mean diameter of 7 nm and 106 nm, respectively. The FTIR spectra of Fe_3O_4@OA confirmed the bonding of OA to the surface of iron oxide, while those of Fe_3O_4@OA@SiO_2 showed the exposed silanol groups. Although MNPs yielded a lower quantity of DNA compared with phenol/chloroform extraction, they showed the potential protection of the integrity of DNA against centrifugal and shear forces. Fe_3O_4@OA@SiO_2 favored more nucleic acid absorption than Fe_3O_4@OA, producing a 1.2 and 1.6 times greater amount of DNA from *Arthrospira platensis* and animal blood respectively. The purity of DNA isolated from *Arthrospira platensis* was also higher than that of animal blood. These findings indicate a new and simple approach for the isolation of DNA from *Arthrospira* genus.

Keywords: Magnetic nanoparticles, Oleic acid coating, Silica coating, DNA isolation, *Arthrospira platensis*, Whole blood

*Correspondence: thuongntl@tdmu.edu.vn

[1] Institute of Applied Technology, Thu Dau Mot University, Binh Duong 75000, Viet Nam
Full list of author information is available at the end of the article



Introduction

DNA isolation is a central procedure in life science and has significant effects on downstream studies such as DNA sequencing and PCR amplification (Ruggieri et al. 2016; Kovačević 2016). There are two principle methods for DNA purification: liquid- and solid-phase separation (Ruggieri et al. 2016). As for the former, organic separation using phenol and chloroform was considered the gold standard (Price et al. 2009) for its high yield and purity of isolated DNA. However, it requires cucumber procedures which involve many steps of pipetting, centrifugation, also the use of toxic organic solvents (Zhou et al. 2013; Min et al. 2014; Corchero and Villaverde 2009).

Solid-phase separation was developed based on the reversible binding acid nucleic to silica particles (Vogelstein and Gillespie 1979), resulting in the commercial application of spin column-based extractions (Ruggieri et al. 2016). Some of the commercially available kits featuring these techniques from Zymo Research, Qiagen, Life technologies have been widely applied to purify DNA due to its high consistency, productivity, and free of toxic chemicals (Price et al. 2009; Tan and Yiap 2009). Magnetic nanoparticles (MNPs) provide the alternative solid-phase purification of DNA (Hawkins et al. 1994; DeAngelis et al. 1995), which has also been well characterized in various studies (Tang et al. 2020; Horak et al. 2007). This method not only shares the similar advances of the spin column over organic separation, but also has the potential for automation, dismissing of the cross-contamination, and exerts fewer effects on DNA structure due to free of centrifugal and shearing forces (Zhou et al. 2013; Tang et al. 2020; Berensmeier 2006).

Iron oxides smaller than 30 nm in diameter usually possess superparamagnetic properties (Xu et al. 2006), enabling them to be well dispersed in lysate solution and evenly absorb DNA in the absence of magnet field (Kovačević 2016). Naked magnetic nanoparticles (Fe_3O_4) could also directly absorb DNA from plasmids (Davies et al. 1998), mammalian cells, and tissues (Saiyed et al. 2006) without reports of being toxic like cobalt ferrite (Lee and Kim 2012) or titanium oxide (Anas et al. 2008). However, the naked MPNs are often agglomerated due to the attractive forces (Berensmeier 2006), which could reduce their biocompatibility and lead to undesirable interactions (Tang et al. 2020; Horak et al. 2007). Thus, surface modifications of MNPs are necessary to maintain stability and facilitate the adsorption of DNA (Horak et al. 2007; Li et al. 2011).

MNPs have been surface-modified by using surfactant, chitosan, silica, cellulose, or polystyrene (Kovačević 2016; Li et al. 2011). Surface coating usually decreases the magnetization of NPs, which is related to the decreased agglomeration and net moment of particles (Ghosh et al. 2011) or lattice defects (Wang et al. 2010). Among them, oleic acid (OA) and silica are two common capping materials because of their good stability, biocompatibility, and straightforward synthetic methods (Li et al. 2011; Ghosh et al. 2011; Chen et al. 2016). Oleic acid is a surfactant with a long hydrocarbon tail. The surface-modified OA

results in the reduced size, decreased agglomeration, and nonpolar solubility of MNPs (Horak et al. 2007; Ghosh et al. 2011; Vogt et al. 2010). Alternatively, silica has also been studied for DNA isolation due to its ability of fast binding and elution of nucleic acid in the presence of chaotropic salts or water, respectively (Rittich et al. 2006; Melzak et al. 1996). The chaotropic agent dehydrates the nucleic acid backbone, forming the cation bridge between nucleic acid and silica surface which can be reversed by adding water and allowing for the elution of absorbed nucleic acids (Tan and Yiap 2009; Melzak et al. 1996). Silica-coated magnetic nanoparticles have also been widely applied for the adsorption of protein and immune cells (Ta et al. 2016) or isolation of DNA from bacteria (Chen et al. 2016), carcinoma cells (Wang et al. 2017), human whole blood (Li et al. 2011), and soil samples (Sebastianelli et al. 2008). However, there is little information reporting the application of coated MNPs to isolate DNA from fungi or cyanobacteria.

Arthrospira genus, multicellular and filamentous cyanobacteria, has gained popularity in food supplements, functional food, and nutraceuticals (Belay 2013; Morin et al. 2010). *Arthrospira* genus contains a high amount of phenolic compounds and proteins but a small amount of genetic material (Ciferri 1983; Xu et al. 2016), which leads to the fluctuating efficiency in DNA isolation. Isolation methods that utilize silica membranes appear to result in an inefficient yield of DNA, while procedures that rely on mechanical beating of the cells by beads seem to exert a strong shearing effect on DNA, rendering DNA degradation (Morin et al. 2010). Other methods mainly applied organic solvents to extract and precipitate DNA. In contrast to *Arthrospira platensis*, DNA from blood samples has been widely isolated by MNPs. However, the high levels of protein in blood can inhibit nucleic acid separation (Ruggieri et al. 2016).

Although MNPs have been widely applied to purify DNA from various samples, less research is on using MNPs to isolate DNA from Arthrospira cells. In this study, we first applied Fe3O4@OA and Fe3O4@OA@SiO2 to purify DNA from *Arthrospira platensis*. The quantity and purity of DNA isolated from *Arthrospira platensis* were evaluated and compared with that from animal blood and other methods including phenol/chloroform and silica-based columns.

Materials and methods

Materials

Arthrospira platensis and animal blood were provided by the Institute of Applied Technology (Thu Dau Mot University, Binh Duong, Vietnam). All analytical grade reagents were purchased from Sigma-Aldrich (St. Louis, MO, USA) unless otherwise mentioned.

Preparation of oleic acid-coated magnetic nanoparticles

Fe_3O_4 nanoparticles were initially synthesized through the ultrasound-assisted co-precipitation method and coated with oleic acid on the surface later (Ding et al. 2012). Briefly, ferric chloride hexahydrate ($FeCl_3{\cdot}6H_2O$, 1.03 g), ferrous chloride tetrahydrate ($FeCl_2{\cdot}4H_2O$, 0.01 mol), and double distilled water (ddH_2O; 40 ml) were added into a round-bottomed flask. The mixture of iron oxide was thoroughly dissolved by ultrasonication at 50 °C for 20 min. Sodium hydroxide solution 0.8 M (40 ml) was dropped into the mixture at the rate of 1 droplet per 2 seconds. After adding NaOH, the mixture was kept sonicated for 1 h to form the black precipitate of magnetic nanoparticles (Fe_3O_4). The magnetic nanoparticles were further coated with oleic acid by the addition of 20 ml of the surfactant and continuous sonication for 1 h. After coating, the obtained Fe_3O_4@OA was washed by absolute EtOH five times by centrifuging for 30 min at 10,000 rpm 4 °C (Hermle Centrifuge Z 216 MK, Germany) and dried at 50 °C for 15 h.

Preparation of silica-coated magnetic nanoparticles

Silica-coated magnetic nanoparticles were further prepared through the Stöber process (Stöber et al. 1968). Fe_3O_4@OA (40 mg) was dispersed in ddH_2O (16.8 ml) at room temperature for 20 min. Subsequently, EtOH (64 ml), NH_3 (4 ml), and tetraethyl orthosilicate (TEOS; 4 ml) were added to the solution under continuous ultrasonic vibration to form silica-coated magnetic nanoparticles. The obtained Fe_3O_4@OA@SiO_2 was rinsed by absolute EtOH five times by centrifuging for 30 min at 10,000 rpm 4 °C (Hermle Centrifuge Z 216 MK, Germany) and dried at 50 °C for 15 h.

Characterization of magnetic nanoparticles

The morphology of synthesized Fe_3O_4@OA and Fe_3O_4@OA@SiO_2 was observed using transmission electron microscopy (TEM, JEM-1400, JEOL, Japan). The size distribution of MNPs was analyzed from TEM photographs using ImageJ (1.52, National Institutes of Health, USA). The Fourier-transform infrared (FTIR) spectra were recorded on a spectrophotometer model (Tensor 27, Bruker, Bremen, Germany). Magnetic nanoparticles were measured at room temperature using vibrating sample magnetometer (VSM, EZ9 MicroSense, USA).

Preparation of crude cell lysates of Arthrospira platensis

Crude cell lysates of *Arthrospira platensis* were prepared by the modified procedure (Rittich et al. 2006). Briefly, *Arthrospira platensis* cells (600 µl) were lysed by lysis buffer (60 µl of sodium dodecyl sulfate (SDS; L3771, Sigma-Aldrich, USA), 15 µl of proteinase K 20 mg/ml

(AM2546, Thermo Fisher Scientific, Invitrogen TM)) at 55 °C for 4 h. After lysis, the insoluble particles were removed by centrifugation (14,500 × g for 5 min), while the soluble polysaccharides were further precipitated with 170 µl of NaCl (5 M) and 135 µl of 10% cetyltrimethylammonium bromide (CTAB, Sigma-Aldrich, USA) at 65 °C for 30 min. The precipitate was subsequently discarded by centrifugation (10,000 × g for 5 min) to obtain the crude cell lysate.

Preparation of crude cell lysates of animal blood

A sample of animal blood (200 µl), 10% SDS (100 µl), and 10 µl of proteinase K (20 mg/ml) were sequentially added to the 1.5 ml Eppendorf. The mixture was then gently mixed and incubated at 65 °C for 30 min to lyse the blood cell.

DNA isolation on magnetic particles

The procedure for DNA isolation was based on the modified reported process (Hawkins et al. 1994). Briefly, lysate samples of *Arthrospira platensis* were mixed with 1 mg of Fe_3O_4@OA or Fe_3O_4@OA@SiO_2 and that of animal blood was mixed with 2 mg of Fe_3O_4@OA or Fe_3O_4@OA@SiO_2. The quantity of MNPs was optimized for each type of samples (Additional file 1: Table S1). Binding buffer (165 µl of 1.25 M NaCl and 0.5% Tween 80 with the ratio of 9:1) was subsequently added to each sample and gently mixed. The mixture was incubated at room temperature for 5 min to form the complexes of nanoparticles and DNA. These complexes were then separated by a magnet (Promega, Madison, WI, USA), followed by the discarding of the supernatant. The immobilized DNA was subsequently rinsed with 100 µl of 70% EtOH thrice. After thorough evaporation, the sample was well agitated in 100 µl of TE buffer (10 mM Tris–HCl, 1 mM EDTA, pH 8) at 65 °C for 10 min to elute DNA. The purified DNA was collected and the nanoparticles were magnetically removed afterward.

DNA isolation on silica column

Silica column kits, AccRive Plan/Food DNA Prekit (KT biotech, Vietnam) and AccuLite Blood DNA Prekit (KT biotech, Vietnam), were used to extract DNA from the crude cell lysates of *Arthrospira platensis* and animal blood, respectively. The procedures involved lysis steps, centrifugation, washing, and elution, which were performed according to the manufacturing instructions.

DNA isolation by organic solvents

The DNA from cell lysate was extracted through the addition of an equal volume of the solution of phenol/chloroform/isoamyl with the ratio of 25:24:1. The sample was further kept on ice for 20 min, followed by centrifugation (10,000 × g for 5 min) at 4 °C. The supernatant was then collected and transferred to a fresh Eppendorf. Absolute EtOH was further added to precipitate DNA at − 20 °C for 30 min. The nucleic acid was collected by centrifugation (10,000 × g for 5 min) at 4 °C, followed by discarding the supernatant. The DNA pellet was air-dried and further dissolved in 100 µl of TE buffer.

Characterization of isolated DNA

Isolated DNA was analyzed by gel electrophoresis. The sample (10 µl) and Gel Red (1.6 µl; Sigma-Aldrich, St. Louis, MO, USA) were mixed and loaded on a 1% agarose gel in TAE buffer (0.04 M tris–acetate and 0.001 M EDTA). The gel was electrophorized at 100 V for 50 min and photographed by UV light at 305 nm. In addition, the content and quality of the eluted DNA were further assessed by ultraviolet spectrophotometry (NanoDrop 2000c, Thermo Scientific, USA). The content of DNA was measured by spectrophotometric quantification at 260 nm. The overall quality was estimated by the absorbance ratio at 260/280.

Statistical analysis

All experiments were conducted at least three independent times whose experimental values were presented in means ± SD. The analysis was performed by GraphPad Prism (8.4.2, GraphPad Software, San 153 Diego, California, USA).

Results

In this study, we synthesized magnetic nanoparticles by co-precipitating divalent and trivalent iron ions under ultrasound vibration and controlled temperature. MNPs were further coated with oleic acid (Fe_3O_4@OA) and silica nanoparticles (Fe_3O_4@OA@SiO_2). The obtained magnetic nanoparticles with modified surfaces were evaluated for size distribution, magnetization, and surface through TEM, vibrating sample magnetometer, and FTIR. Two types of magnetic particles were further used as adsorbents for the isolation of genetic DNA from *Arthrospira platensis* and animal blood (Fig. 1). The quantity and quality of DNA extracted by Fe_3O_4@OA and Fe_3O_4@OA@SiO_2 were determined by gel electrophoresis and ultraviolet spectroscopy and compared with that isolated by organic separation and silica column.

TEM images

The morphology of Fe_3O_4@OA and Fe_3O_4@OA@SiO_2 was evaluated by TEM images that at least 100 MNPs were measured from each sample using ImageJ. Fe_3O_4@OA displayed the nanosphere shape with a narrow distribution (Fig. 2A). The diameter of Fe_3O_4@OA was

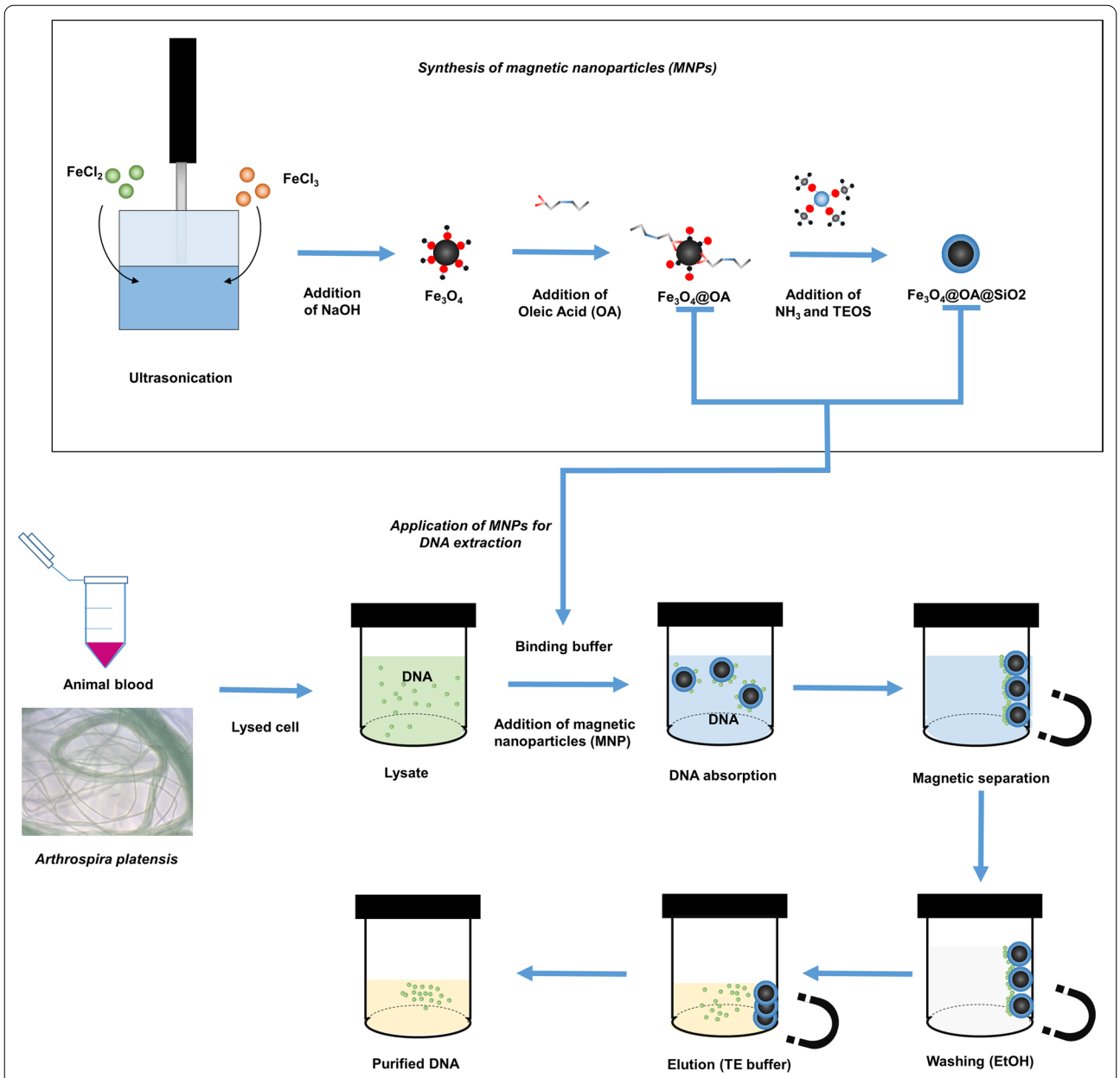


Fig. 1 Schematic study. Oleic acid-coated magnetic nanoparticles (Fe_3O_4@OA) and silica-coated magnetic nanoparticles (Fe_3O_4@OA@SiO_2) are prepared. These particles are further applied for the isolation of DNA from *Arthrospira platensis* and animal blood

ranging from 5 to 12 nm with the average diameter of approximately 7 nm and 66.7% of the distribution in the range of 6–10 nm (Fig. 2B). TEM image of Fe_3O_4@OA@SiO_2 displayed a core–shell structure in which the multicores of Fe3O4 were observed as dark dots in the center and the silica shells covered as the gray area outside (Fig. 3A). The average diameter of Fe_3O_4@OA@SiO_2 was roughly 106 nm, which mainly distributed in the range from 85 to 115 nm (Fig. 3B).

FTIR spectra

The surfaces of Fe_3O_4@OA and Fe_3O_4@OA@SiO_2 were examined using FITR (Fig. 4). The FTIR spectra of Fe_3O_4@OA and Fe_3O_4@OA@SiO_2 showed the peaks at 1632 cm^{-1} and 3437 cm^{-1} that corresponded to –OH bonds and 575 cm^{-1} which were attributed to Fe–O vibrations of Fe_3O_4 (Li et al. 2011; Ta et al. 2016). The FTIR spectra of Fe_3O_4@OA displayed additional peaks at 2851 cm^{-1} and 2922 cm^{-1} which were assigned to the stretching vibrations of CH_3 and CH_2 groups in

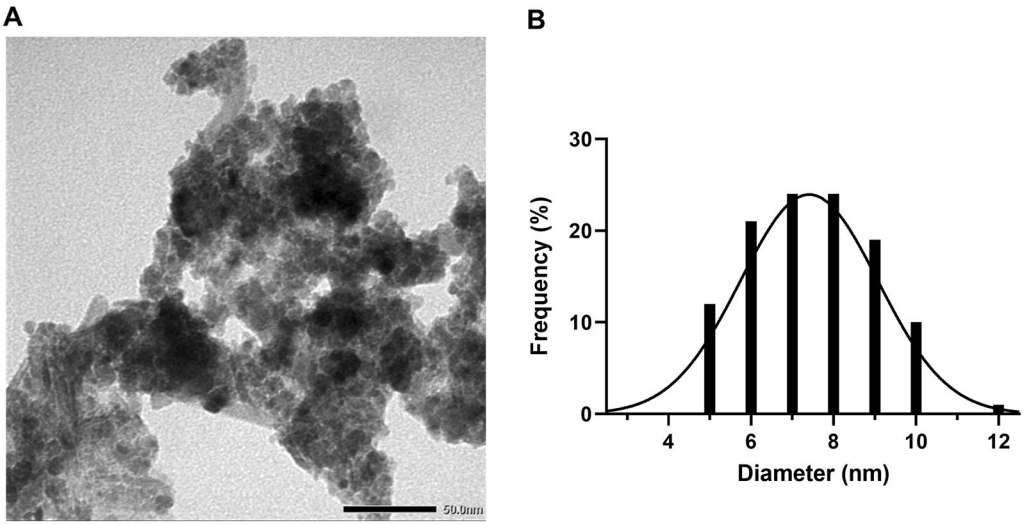


Fig. 2 Transmission electron microscopy (TEM) image and size distribution of oleic acid-coated magnetic nanoparticles (Fe_3O_4@OA). (**A**) TEM image, scale bar: 50 nm. (**B**) Size distribution, $n = 100$

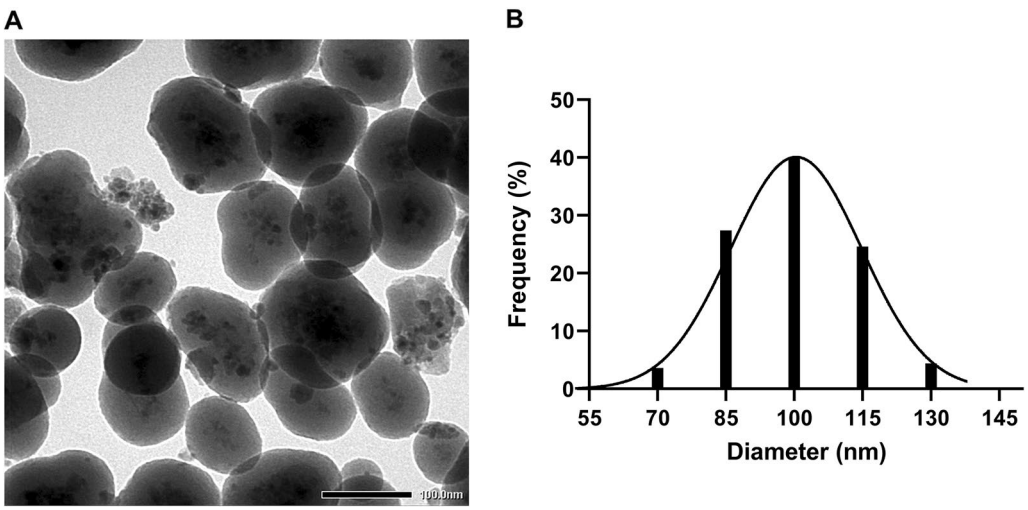


Fig. 3 Transmission electron microscopy (TEM) image and size distribution of silica-coated magnetic nanoparticles (Fe_3O_4@OA@SiO_2). (**A**) TEM image, scale bar: 100 nm. (**B**) Size distribution, $n = 100$

the carbon backbone of OA (Ghosh et al. 2011; Vogt et al. 2010; Nalle et al. 2019). A new band appeared at 1464 cm^{-1} corresponding to the stretching vibration of COO-. FTIR spectrum confirmed the capping of oleic acid onto the surface of iron oxide nanoparticles. Fe_3O_4@OA@SiO_2 showed new peaks at 467 cm^{-1}, 802 cm^{-1}, 959 cm^{-1}, and 1099 cm^{-1} which were assigned to the asymmetric vibration of Si–O-Si bonds, the bending vibration of the Si–O–Si, the symmetric stretching of Si–OH bonds, and the symmetric stretching of the Si–O–Si, respectively (Li et al. 2011; Vogt et al. 2010; Ta et al. 2016). The FTIR spectra confirmed that silica nanoparticles were successfully coated on the surface of Fe_3O_4.

Magnetic properties

The magnetic properties of synthesized MNPs were measured at room temperature using VSM (Fig. 5). The magnetization curves showed the typical superparamagnetic behavior with zero coercivity and remanence on the magnetization loops. The saturation magnetization values (Ms) of Fe_3O_4@OA and Fe_3O_4@OA@SiO_2 were approximately 80.0 emu/g and 19.5 emu/g, respectively.

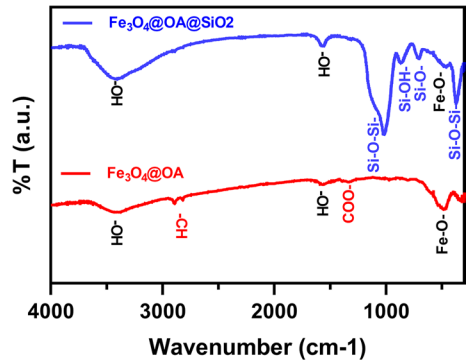


Fig. 4 The FTIR spectra. (**A**) Fe_3O_4@OA. (**B**) Fe_3O_4@OA@SiO_2

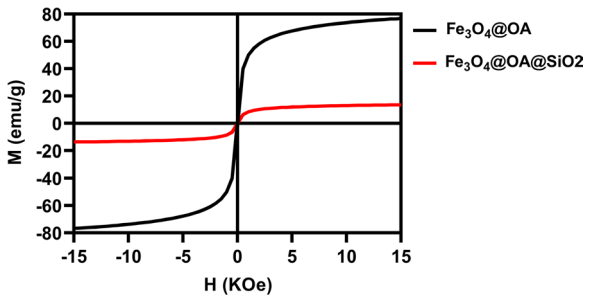


Fig. 5 Magnetization curves of the magnetic nanoparticles obtained by vibrating sample magnetometer at room temperature

The decrease in the Ms value of Fe_3O_4@OA@SiO_2 was attributed to the coating of silica on the magnetic properties of the NPs.

Extraction of DNA from Arthrospira platensis

Molecular weight and the degradation of isolated DNA were evaluated through gel electrophoresis. The gel displayed a large size of isolated DNA which was roughly 15–20 kb (Fig. 5A). The DNA isolated by phenol/chloroform, Fe_3O_4@OA, and Fe_3O_4@OA@SiO_2 exhibited sharp patterns, while that by the commercial silica column showed smeared fragments (Fig. 5A). The yields of DNA isolated were further determined using ultraviolet spectrophotometry (Table 1). Phenol extraction yielded the highest DNA content (approximately 20.5 μg), which was consistent with the brightest electrophoresis patterns. The average yields of DNA isolated by Fe_3O_4@OA, Fe_3O_4@OA@SiO_2, and silica column were 2.14, 2.61, and 2.89 μg, respectively. In addition, the absorbance ratio (OD 260/280) of DNA isolated from Fe_3O_4@OA and Fe_3O_4@OA@SiO_2 was approximately 1.5, while that from phenol/chloroform and silica columns were 2.0 and 1.9, respectively.

Extraction of DNA from animal blood

Gel electrophoresis indicated the large molecular sizes of the extracted DNA, which were greater than 20 kb (Fig. 6A). DNA extracted by phenol/chloroform was degraded into smears and small fragments, whereas this was not observed in those extracted by Fe_3O_4@OA, Fe_3O_4@OA@SiO_2, and silica columns. The phenol/chloroform method isolated the highest content of DNA (roughly 10.4 μg), while Fe_3O_4@OA, Fe_3O_4@OA@SiO_2, and silica column yielded 2.3, 3.7, and 0.36 μg of DNA content, respectively (Table 2). The absorbance ratios of DNA isolated from Fe_3O_4@OA, Fe_3O_4@OA@SiO_2 were low, approximately 1.1 in comparison with those extracted from phenol/chloroform and silica columns were 2.1 and 1.9, respectively (Table 2).

Discussion

We successfully synthesized OA-coated and silica-coated MNPs and applied them to purify DNA from cyanobacteria and animal blood (Fig. 1). Silica was more favorable for the binding of nucleic acid than OA. That may be due to the hydrophilic property of the silica surface and the aided binding conditions which were created by adding chaotropic salts to the lysates. In addition, MNPs isolated higher purity of DNA from *Arthrospira platensis* than the blood samples which could be attributed to the different nature of the samples. MNPs resulted in the lower yield of DNA than the phenol/chloroform. However, the structure of DNA isolated by MNPs was well maintained than the solvent extraction and spin column methods.

OA-coated magnetic nanoparticles dispersed in a narrow distribution with an average diameter of 7 nm (Fig. 2). That was smaller than the previously reported size of Fe_3O_4, roughly 10–16 nm (Unal et al. 2010; Mehta et al. 1997). The smaller size could be attributed to the coating of OA, which might contribute to stabilizing,

Table 1 Comparison of methods to separate DNA from *Arthrospira platensis*

	Method			
	Phenol/chloroform	**Fe_3O_4@OA**	**Fe_3O_4@OA@SiO_2**	**Silica column**
DNA yield (μg)	20.53 ± 1.6	2.14 ± 0.39	2.61 ± 0.24	2.89 ± 0.10
A260/A280	2.03 ± 0.01	1.49 ± 0.01	1.43 ± 0.01	1.9 ± 0.01

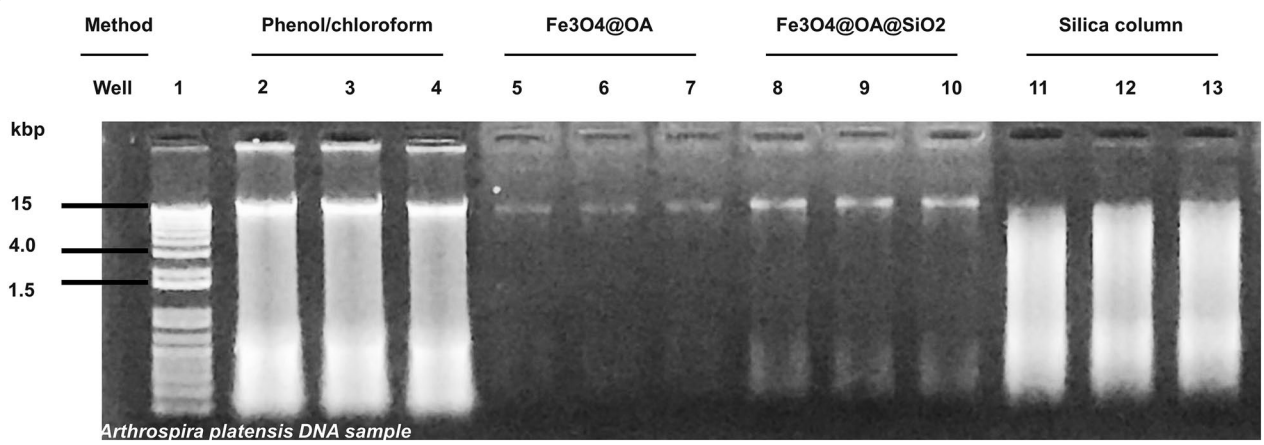


Fig. 6 Agarose gel electrophoresis of DNA isolated from *Arthrospira platensis*. Lane 1: 1 kb plus DNA ladder (Invitrogen); DNA are extracted through phenol/chloroform (lanes 2–4), Fe_3O_4@OA (lanes 5–7), Fe_3O_4@OA@SiO_2 (lane 8–10), silica column (lane 11–13)

Table 2 Comparison of methods ro isolate DNA from whole blood sample

	Method			
	Phenol/Chloroform	**Fe_3O_4@OA**	**Fe_3O_4@OA@SiO_2**	**Silica column**
DNA yield (μg)	10.32 ± 5.80	2.3 ± 0.13	3.7 ± 0.77	0.36 ± 0.05
A260/A280	2.05 ± 0.09	1.13 ± 0.06	1.05 ± 0.01	1.94 ± 0.23

reducing the size and agglomeration of MNPs (Ghosh et al. 2011; Nalle et al. 2019; Zhang et al. 2006). The FTIR spectra showed the stretching vibrations of the CH– bond at 2851 cm^{-1} and 2922 cm^{-1} and the COO- bond at the new peak of 1464 cm^{-1} (Fig. 4). These spectra indicated that OA formed carboxyl bonds with the surface of MNPs (Wang et al. 2010; Nalle et al. 2019; Zhang et al. 2006). The Diameter of MNPs increased to 106 nm after coating silica, which was mainly due to the increase in the size of the shell structure. The silica shell was amorphous with no formation of crystallographic planes (Fig. 3). Furthermore, the FTIR spectra showed the presence of silanol groups (peak at 802 cm^{-1}) on the surface of MNP (Fig. 4). The silanol group makes Fe_3O_4@OA@SiO_2 hydrophilic and facile surface modification, while the hydrophobic properties of OA could limit their bio-applications (Vogt et al. 2010). Coating silica further decreased the magnetization of Fe3O4@OA from 80.0 to 19.5 emu/g (Fig. 5). The previous studies showed that Ms values of surface-modified MNPs were often lower than that of naked MNPs (92 emu/g) (Li et al. 2011; Han et al. 1994). Another study also reported that the Ms value of core–shell magnetic particles was inversely corresponding to the thickness of silica shells (Vogt et al. 2010). This could be attributed to the reduction in agglomeration of particles, leading to the faster spin relaxation, in turn, decreasing magnetization (Vogt et al. 2010). However, the value Ms of Fe3O4@OA@SiO2 was considered practical for bio-application (Vogt et al. 2010; Ta et al. 2016).

We further applied coated nanoparticles for the solid-phase supported isolation of DNA from *Arthrospira platensis* and animal blood. Gel electrophoresis showed a molecular weight of 15–20 kb for *Arthrospira platensis* (Fig. 6) and of greater than 20 kb for a blood sample (Fig. 7). Those were consistent with the previous report on the molecular size of DNA from *Arthrospira platensis* (Morin et al. 2010) and animal blood. Fe_3O_4@OA@SiO_2 isolated a higher amount of DNA compared with Fe_3O_4@OA, specifically 1.2-fold and 1.6-fold greater in the case of *Arthrospira platensis* and animal blood, respectively (Tables 1, 2). This might be because silica favored the binding of DNA molecules (Li et al. 2011; Chen et al. 2016; Wang et al. 2017). Previous studies showed that the fast binding of DNA to the silica surface occurred under the condensed condition caused by adding chaotropic salts. A chaotropic agent dehydrates the nucleic acid backbone, forming the cation bridge between nucleic acid and silica surface and can be reversed by adding

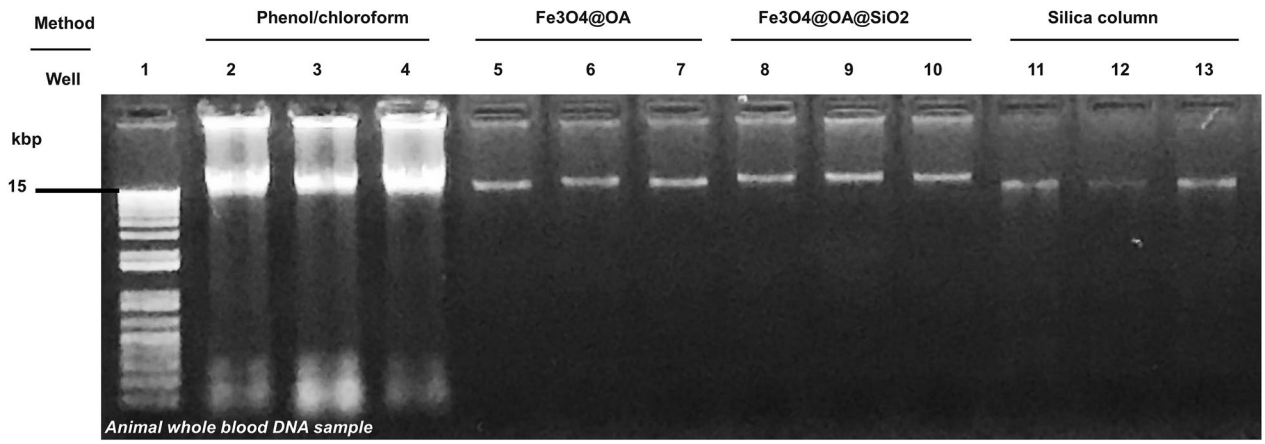


Fig. 7 Agarose gel electrophoresis of DNA isolated from whole blood animal. Lane 1: 1 kb plus DNA ladder (Invitrogen); DNA are extracted through phenol/chloroform (lanes 2–4), Fe_3O_4@OA (lanes 5–7), Fe_3O_4@OA@SiO_2 (lanes 8–10), silica column (lanes 11–13)

water and allowing for elution of nucleic acid (Tan and Yiap 2009; Melzak et al. 1996). In this study, we applied a binding buffer containing salts and surfactant (165 µl of 1.25 M NaCl and 0.5% Tween 80 with the 9: 1) to facilitate the binding of DNA. In addition, DNA could bind to silanol group on the surface of silica due to the hydrogen bonding in the presence of chaotropic salts (Kovačević 2016; Rittich et al. 2006). Otherwise, OA capping would result in oil soluble nanoparticles (Ghosh et al. 2011; Vogt et al. 2010). The hydrophobicity of the OA coating may lead to a decrease in DNA absorption to the surface of NPs, resulting in a lower DNA yield of DNA than Fe_3O_4@OA@SiO_2.

Naked MNPs and silica are widely studied for their biocompatibility (Kovačević 2016; Vogt et al. 2010). Saiyed Z et al. applied Fe3O4 to purify DNA from tissues and whole blood, producing 1.8–2.0 µg of DNA and 1.3 times higher than the Qiagen spin column (Saiyed et al. 2006). That quantity of DNA was similar to the yield of DNA isolated from the blood sample (2.3–3.7 µg) which was also higher than the yield of the spin column (0.36 µg) (Table 2). These results might indicate that MNPs can purify DNA from high protein samples better than the spin column, which could be due to the well disperse of MNPs in the lysate supporting the absorption of DNA in comparison to the silica membrane. Sebastianelli et al. also studied the application of silica nanomagnetite particles to purify DNA from the soil sample. The results were reported that silica-coated MNPs have approximately two times higher quantity than the phenol/chloroform method and almost four times less expensive than another extraction kit (Sebastianelli et al. 2008). Compared to our study, MNPs yielded a lower quantity than phenol/chloroform extraction (Table 1). This may be due to the nature of *Arthrospira cells*. This genus contains approximately 4% nucleic acid per dry weight while that of *Bacillus subtilis* was approximately 20% (Ciferri 1983). Furthermore, *Arthrospira platensis* is also rich in polyphenols and polysaccharides, which could co-absorb on MNPs (Philippis and Vincenzini 1998), resulting in a low quantity of DNA isolation. However, DNA structure showed the sharp band without smear like phenol/chloroform extraction or degraded as spin column (Fig. 6), whereas previous studies also reported the degradation of DNA from *Arthrospira platensis* isolated from glass bead and silica membrane (Morin et al. 2010), suggesting that these methods induced more negative effects of shear force on DNA structure than MNPs.

Conclusion

In summary, we successfully synthesized modified surface magnetic nanoparticles through co-precipitation and solgel process under ultrasonic vibration. Both Fe_3O_4@OA and Fe_3O_4@OA@SiO_2 proved the capability in adsorption and isolation of DNA from *Arthrospira platensis* and animal blood, in which Fe_3O_4@OA@SiO_2 provided a higher binding efficiency than Fe_3O_4@OA. The extracted DNA maintained integrity due to the free shearing and centrifugal force procedure. The optimized procedures in lysed cells and DNA adsorption would be further studied for a higher quality of isolated DNA.

Abbreviations

MNPs: Magnetic nanoparticles; TEM: Transmission electron microscopy; FTIR: Fourier-transform infrared spectroscopy; OA: Oleic acid; TEOS: Tetraethyl orthosilicate; ddH_2O: Double distilled water; UV: Ultraviolet; VSM: Vibrating sample magnetometer.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40543-022-00337-2.

Additional file 1. Tables S1. DNA yields corresponding to the quantity of magnetic nanoparticles.

Acknowledgements
Transmission electron microscopy was performed at Ho Chi Minh City University of Technology.

Author contributions
L-TTN contributed to conceptualization, methodology, and project administration. NHTL and HKTT performed investigation. KDN was involved in investigation, formal analysis, writing—original draft, and writing—review and editing. All authors read and approved the final manuscript.

Funding
This research is funded by Thu Dau Mot University.

Availability of data and materials
All data generated or analyzed during this study are included in this published article.

Declarations

Competing interests
The authors declare that there are no competing financial interests or personal relationships that could have appeared to influence the work reported in the present study.

Author details
[1]Institute of Applied Technology, Thu Dau Mot University, Binh Duong 75000, Viet Nam. [2]Faculty of Materials Science and Technology, University of Science, Ho Chi Minh City, Viet Nam. [3]Vietnam National University, Ho Chi Minh City, Viet Nam. [4]Center for Innovative Materials and Architectures (INOMAR), Ho Chi Minh City, Viet Nam.

Received: 7 October 2021 Accepted: 28 July 2022
Published: 5 August 2022

References

Anas A, Akita H, Harashima H, Itoh T, Ishikawa M, Biju V. Photosensitized breakage and damage of DNA by CdSe— ZnS quantum dots. J Phys Chem B. 2008;112(32):10005–11.
Belay A. Biology and industrial production of Arthrospira (Spirulina). In: Handbook of microalgal culture: applied phycology biotechnology; 2013.p. 339–358.
Berensmeier S. Magnetic particles for the separation and purification of nucleic acids. Appl Microbiol Biotechnol. 2006;73(3):495–504.
Chen Y, Lin J, Jiang Q, Chen Q, Zhang S. A magnetic nanoparticle based nucleic acid isolation and purification instrument for DNA extraction of *Escherichia coli* O157: H7. J Nanosci Nanotechnol. 2016;16(3):2296–300.
Ciferri O. Spirulina, the edible microorganism. Microbiol Rev. 1983;47(4):551.
Corchero JL, Villaverde A. Biomedical applications of distally controlled magnetic nanoparticles. Trends Biotechnol. 2009;27(8):468–76.
Davies MJ, Taylor JI, Sachsinger N, Bruce IJ. Isolation of plasmid DNA using magnetite as a solid-phase adsorbent. J Anal Biochem. 1998;262(1):92–4.
De Philippis R, Vincenzini M. Exocellular polysaccharides from cyanobacteria and their possible applications. FEMS Microbiol Rev. 1998;22(3):151–75.
DeAngelis MM, Wang DG, Hawkins TL. Solid-phase reversible immobilization for the isolation of PCR products. Nucleic Acids Res. 1995;23(22):4742.
Ding H, Zhang Y, Wang S, Xu J, Xu S, Li G. Fe3O4@ SiO2 core/shell nanoparticles: the silica coating regulations with a single core for different core sizes and shell thicknesses. J Chem Mater. 2012;24(23):4572–80.
Ghosh R, Pradhan L, Devi YP, Meena S, Tewari R, Kumar A, Sharma S, Gajbhiye N, Vatsa R, Pandey BN. Induction heating studies of Fe3O4 magnetic nanoparticles capped with oleic acid and polyethylene glycol for hyperthermia. J Mater Chem. 2011;21(35):13388–98.
Han D, Wang J, Luo H. Crystallite size effect on saturation magnetization of fine ferrimagnetic particles. J Magn Magn Mater. 1994;136(1–2):176–82.
Hawkins TL, O'Connor-Morin T, Roy A, Santillan C. DNA purification and isolation using a solid-phase. Nucleic Acids Res. 1994;22(21):4543.
Horak D, Babič M, Mackova H, Beneš MJ. Preparation and properties of magnetic nano-and microsized particles for biological and environmental separations. J Sep Sci. 2007;30(11):1751–72.
Kovačević N. Magnetic beads based nucleic acid purification for molecular biology applications. In: Sample preparation techniques for soil, plant, and animal samples, Springer; 2016. p. 53–67.
Lee DS, Kim S. Gene expression profiles for genotoxic effects of silica-free and silica-coated cobalt ferrite nanoparticles. J Nucl Med. 2012;53(1):106–12.
Li G, Shen B, He N, Ma C, Elingarami S, Li Z. Synthesis and characterization of Fe3O4@ SiO2 core–shell magnetic microspheres for extraction of genomic DNA from human whole blood. J Nanosci Nanotechnol. 2011;11(12):10295–301.
Mehta R, Upadhyay R, Charles S, Ramchand C. Direct binding of protein to magnetic particles. Biotechnol Tech. 1997;11(7):493–6.
Melzak KA, Sherwood CS, Turner RF, Haynes CA. Driving forces for DNA adsorption to silica in perchlorate solutions. J Colloid Interface Sci. 1996;181(2):635–44.
Min JH, Woo M-K, Yoon HY, Jang JW, Wu JH, Lim C-S, Kim YK. Isolation of DNA using magnetic nanoparticles coated with dimercaptosuccinic acid. Anal Biochem. 2014;447:114–8.
Morin N, Vallaeys T, Hendrickx L, Natalie L, Wilmotte A. An efficient DNA isolation protocol for filamentous cyanobacteria of the genus Arthrospira. J Microbiol Methods. 2010;80(2):148–54.
Nalle F, Wahid R, Wulandari I, Sabarudin A. Synthesis and characterization of magnetic fe3o4 nanoparticles using oleic acid as stabilizing agent. Rasayan J Chem. 2019;12(1):14–21.
Price CW, Leslie DC, Landers JP. Nucleic acid extraction techniques and application to the microchip. Lab Chip. 2009;9(17):2484–94.
Rittich B, Španová A, Horák D, Beneš M, Klesnilová L, Petrová K, Rybnikář A. Isolation of microbial DNA by newly designed magnetic particles. Colloids Surf B Biointerfaces. 2006;52(2):143–8.
Ruggieri J, Kemp R, Forman S, Eden MEV. Techniques for nucleic acid purification from plant, animal, and microbial samples. In: Sample preparation techniques for soil, plant, and animal samples, Springer; 2016. p. 41–52.
Saiyed Z, Bochiwal C, Gorasia H, Telang S, Ramchand C. Application of magnetic particles (Fe3O4) for isolation of genomic DNA from mammalian cells. Anal Biochem. 2006;356(2):306–8.
Sebastianelli A, Sen T, Bruce IJ. Extraction of DNA from soil using nanoparticles by magnetic bioseparation. Lett Appl Microbiol. 2008;46(4):488–91.
Stöber W, Fink A, Bohn E. Controlled growth of monodisperse silica spheres in the micron size range. J Colloid Interface Sci. 1968;26(1):62–9.
Ta TKH, Trinh M-T, Long NV, Nguyen TTM, Nguyen TLT, Thuoc TL, Phan BT, Mott D, Maenosono S, Tran-Van H. Synthesis and surface functionalization of Fe3O4-SiO2 core-shell nanoparticles with 3-glycidoxypropyltrimethoxysilane and 1, 1′-carbonyldiimidazole for bio-applications. Colloids Surf A Physicochem Eng Asp. 2016;504:376–83.
Tan SC, Yiap BC. DNA, RNA, and protein extraction: the past and the present. J Biomed Biotechnol. 2009;2009:1.
Tang C, He Z, Liu H, Xu Y, Huang H, Yang G, Xiao Z, Li S, Liu H, Deng Y. Application of magnetic nanoparticles in nucleic acid detection. J Nanobiotechnol. 2020;18:1–19.
Unal B, Durmus Z, Kavas H, Baykal A, Toprak M. Synthesis, conductivity and dielectric characterization of salicylic acid–Fe3O4 nanocomposite. Mater Chem Phys. 2010;123(1):184–90.
Vogelstein B, Gillespie D. Preparative and analytical purification of DNA from agarose. Proc Natl Acad Sci. 1979;76(2):615–9.
Vogt C, Toprak MS, Muhammed M, Laurent S, Bridot J-L, Müller RN. High quality and tuneable silica shell–magnetic core nanoparticles. J Nanopart Res. 2010;12(4):1137–47.
Wang CY, Hong JM, Chen G, Zhang Y, Gu N. Facile method to synthesize oleic acid-capped magnetite nanoparticles. Chin Chem Lett. 2010;21(2):179–82.

Wang J, Ali Z, Si J, Wang N, He N, Li Z. Simultaneous extraction of DNA and RNA from hepatocellular carcinoma (Hep G2) based on silica-coated magnetic nanoparticles. J Nanosci Nanotechnol. 2017;17(1):802–6.
Xu X, Deng C, Gao M, Yu W, Yang P, Zhang X. Synthesis of magnetic microspheres with immobilized metal ions for enrichment and direct determination of phosphopeptides by matrix-assisted laser desorption ionization mass spectrometry. J Adv Mater. 2006;18(24):3289–93.
Xu T, Qin S, Hu Y, Song Z, Ying J, Li P, Dong W, Zhao F, Yang H, Bao Q. Whole genomic DNA sequencing and comparative genomic analysis of *Arthrospira platensis*: high genome plasticity and genetic diversity. DNA Res. 2016;23(4):325–38.
Zhang L, He R, Gu H-C. Oleic acid coating on the monodisperse magnetite nanoparticles. Appl Surf Sci. 2006;253(5):2611–7.
Zhou Z, Kadam US, Irudayaraj J. One-stop genomic DNA extraction by salicylic acid-coated magnetic nanoparticles. Anal Biochem. 2013;442(2):249–52.

Publisher's Note