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Magnetite (Fe_3O_4) Nanoparticles Synthesis and Anti Green Peach Aphid Activity (*Myzuspersicae* Sulzer)

Hassan M. Asoufi[1], Tawfiq M. Al-Antary[1], Akl M. Awwad[2]

Abstract

The present study deals with rapid, green method and large-scale synthesis of magnetite nanoparticles (Fe_3O_4NPs) by *Uncaria tomentosa* leaves aqueous extract at ambient temperature. Crystal growth of magnetite nanoparticles using the processor; ferrous chloride ($FeCl_2$), ferric chloride ($FeCl_3$) and *U. tomentosa* leaves aqueous extract was formed within 5min at room temperature. Fe_3O_4NPs synthesized using prucessor $FeCl_2$ have advantage due to *U. tomentosa* acts as partial oxidizing agent Fe(II) to Fe(III) and then reducing agent to form magnetite nanoparticles ($FeO.Fe_2O_3$) and at the same time gave smaller average particle size 20nm. Synthesized Fe_3O_4NPs were characterized by Ultra-violet visible spectrophotometer (UV-vis), Fourier transform infrared spectroscopy (FT-IR), Transmission electron microscopy (TEM), and X-ray diffraction (XRD). Magnetite nanoparticles showed better green peach aphid activity than reference.

Keywords: Green synthesis; Magnetite nanoparticles; *Uncaria tomentosa*; Green peach aphid

1. Introduction

Magnetite (Fe_3O_4) is magnetic iron oxide encountered in many biological and technological applications. The particle size and shape of magnetite nanoparticles allows tuning their properties to different applications such as targeted drug delivery, cancer diagnostic, magnetic resonance imaging, catalysts, pharmaceuticals, biomedicine, and agriculture. Various routes and methods have been developed for synthesis magnetite nanoparticles (Fe_3O_4NPs) such as co-precipitation method (Petcharoen and Sirivat, 2012), solvothermal reduction method (Hou et al., 2003, Ou et al., 2010), thermal decomposition method (Chin et al., 2011, Angermann and Töpfer, 2008), electrochemical synthesis (Cabrera and Gutierrez, 2008), sol-gel method (Xu et al., 2007), W/O micro-emulsion (Lu et al., 2004), via a solvent-free thermal decomposition route (Maity et al., 2009), hydrothermal synthesis (Ge et al., 2009, Iwasaki et al., 2012), polyol method (Vega-Chacón et al., 2016), high temperature phase reaction of iron acetate in phenyl ether with alcohol (Sun and Zeng, 2002) and by high energy ball milling (de Carvalho et al., 2013). All these methods and routes of synthesis require extra purification steps, reaction times, hazardous by-products, high temperature and difficulty of scale-up, therefore researchers concentrated on the green routes for synthesis magnetite nanoparticles (Fe_3O_4NPs) due to an eco-friendly, cost-effective and non-toxic routes by using plant extracts such as carob leaf extract (Awwad and Salem, 2012), Pistachio leaf extract (Salem et al., 2013), *Kappaphycus alvarezii* extract (Yew et al., 2016), *Sargassum muticum* aqueous extract (Mahdavi et al., 2013), *Dhatura innoxia* plant extract (Das et al., 2014), *Caricaya Papaya* Leaves (Latha1 and Gowri, 2014), *Azadirachta indica* leaf extract (Maheswari and Reddy, 2016), *Tridax procumbens* leaf extract (Senthil and Ramesh, 2012), *Averrhoa carambola* (Ahmed et al., 2015), *Jatropha gosspifolia* leaves (Karkuzhali and Yogamoorthi, 2015), and *hordeum vulgare* and *Rumexacetosa* plants (Valentin et al., 2014).

This research workwas carried out to study the effect of magnetite (Fe_3O_4NPs) nanoparticles on green peach aphid. A facile, eco-friendly and green route was used for synthesis magnetite nanoparticles using *U. tomentosa* leaf aqueous extract.

[1] Department of Plant Protection, School of Agriculture, The University of Jordan, Amman 11942, Jordan.
[2] Department of Materials Science, Royal Scientific Society, El Hassan Science City, Amman 11941, Jordan

2. Experimental

2. 1. Materials

Ferrous chloride ($FeCl_2.4H_2O$, 98%) and ferric chloride ($FeCl_3$, 99.99%) were supplied by Sigma-Aldrich. De-ionized water was used in all experimental work. *U. tomentosa* is a liana deriving its name from hook-like thorns that resemble the claws of a cat. *U. tomentosa* can grow to a length of up to 30 m, climbing by means of these thorns. The leaves are elliptic with a smooth edge, and grow in opposing pairs. Cat's claw leaves were collected from the campus of Royal Scientific Society, Amman, Jordan.

2.2. Plant aqueous extract of *Uncaria tomentosa*

U. tomentosa leaves, **Figure 1** were washed several times by water to remove dust and left to dry for two weeks at room temperature in our laboratory. Afterwards, dried leaves were crushed and ground to give fine powder. 20g of leaves powder of *U. tomentosa* were boiled in 500ml de-ionized water for 10min and then filtered on Whatmann filter paper to obtain an aqueous yellow extract. The aqueous extract was kept in tight glass bottle for further experimental work,

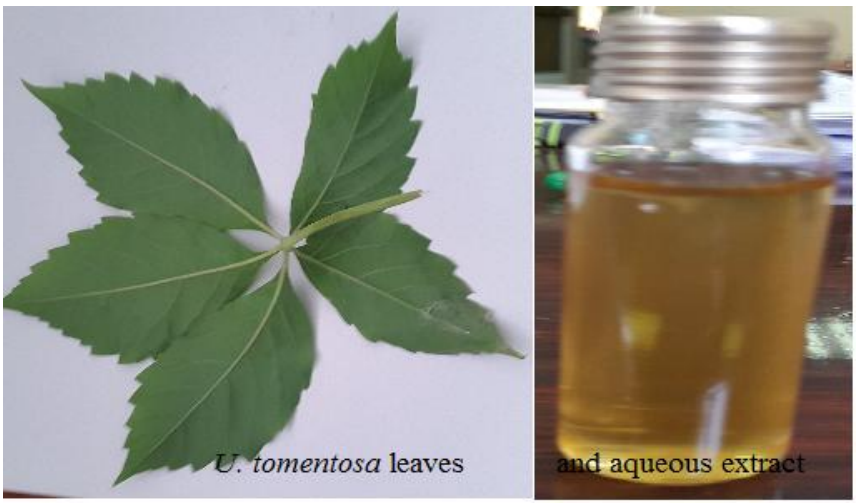

Figure 1. *U.tomentosa* leaves and aqueous e4xtract

2.3. Green synthesis of magnetite nanoparticles (Fe_3O_4NPs)

2.3.1. Synthesis from ferrous chloride ($FeCl_2.4H_2O$) prucessors

In a typical reaction, 1.2g of $FeCl_2$ was dissolved in 400ml de-ionized water under continuous stirring at room temperature (27°C). Afterwards, *U. tomentosa* aqueous extract is added drop by drop, the pale brown color of ferrous chloride solution changed very fast to deep brown color and then to dark color with 2 min. Ratio of $FeCl_2$ solution to the aqueous extract of *U. tomentsa* was 40:1. For analysis, the obtained magnetite nanoparticles were washed three times with de-ionized water and with ethanol to obtain magnetite nanoparticles powder for XRD, SEM, TEM, FT-IR analysis.

2.3.2. Synthesis from ferrous chloride ($FeCl_2.4H_2O$) and ferric chloride ($FeCl_3$) prucessors

In a typical reaction, 1.6g ferric chloride ($FeCl_3$) was dissolved in 400ml de-ionized water under continuous stirring at room temperature (27°C). Afterwards, 10ml of aqueous extract of *U. tomentsa* is added drop by drop to ferric chloride solution, Color of the mixture $FeCl_3$/*U.tomentsa* changed to deep brown color. Then 0.8g $FeCl_2$ /100ml de-ionized water solution is added drop by drop to the mixture of $FeCl_3$/*U.tomentsa*, very fast changed in the color of the mixture within 1min to grey-black color indicating the formation of magnetite nanoparticles.

2.4. Characterization techniques

Magnetite nanoparticles were characterized by different techniques: UV-vis spectroscopy (Shimadzu UV-1601), X-ray diffraction (XRD-6000), fourier transform infrared (FT-IR, IR-Prestige-21 Shimaduz), and transmission electron microscopy (TEM, Hitachi 7600 machine).

2.5. Aphicidal effect of synthesized (Fe_3O_4NPs) on the green peach aphid (GPA)

2.5.1. GPA culture preparation and rearing:

Two cultures of the GPA were prepared. Pure culture of the GPA from infesting pepper plant by adults of the GPA was collected from Ghor al Safi (Jordan) reared under greenhouse conditions in the University of Jordan and considered as a source culture for all experiments of the study. Another culture was on green pepper plants in the growth chamber under lab conditions at Shouback center for agricultural research and extension (20-24^{o}C and 16L:8D photoperiod) to get high population of the GPA. New pepper transplants were provided as needed for both cultures. To avoid resistance, GPA was reared for 10 generations on pepper plant before used in the study.

2.5.2 Toxicity of green synthesized magnetite (Fe_3O_4)NPson the GPA:

Different concentrations of Fe_3O_4NPs were prepared in 100 ml final volume. Dipping method in which infested leaves of the pepper plants by GPA (50- 60 apterous aphid individual/leaves) were used. Leaf disks were dipped in each concentration for 5 sec then placed in 9 cm Petri dishes having wetted filter paper. Petri dish covered by led with ventilation holes were placed under lab conditions (16 L: 8 D) period and 20-25^{o}C. Each concentration was represented by 6 replicates. Individuals of the GPA were grouped in two groups represented 1st and 2^{ed}nymphal instar named early instars as group one and 3^{ed} and 4thnymphal instar named late instars as the other group. Mortality percent was calculated for 24h, 48h and 72h after the treatment. Fine brush was used to assess mortality under dissecting binocular microscope. Mortality assessment was based on lack of antenna and/ or leg movements

3. Results and discussion

3.1. UV-vis spectroscopic analysis

Magnetite nanoparticles synthesized by *U. tomentosa* leaves aqueous extract, which acts as oxidizing and stabilizing agent was monitored by the UV-vis spectrophotometer, An absorbance spectrum, **Figure 2** was observed in each spectrum at 238nm which is characteristic of magnetite nanoparticles. No other peaks were observed in the spectrum, indicating the high purity of the synthesized magnetite nanoparticles by this fast and green method.

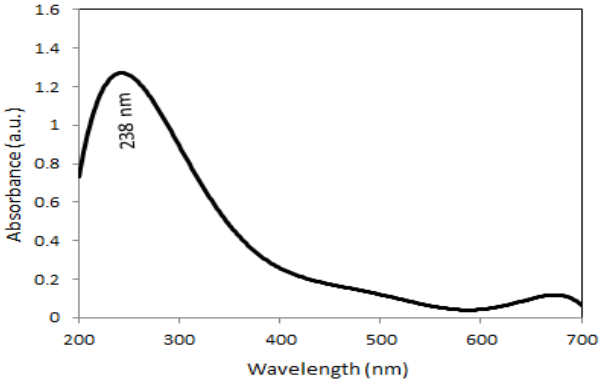

Figure 2. UV-vis spectrum of synthesized magnetite nanoparticles

3.2. X-ray diffraction (XRD) analysis

XRD pattern showed numbers of Bragg's reflections that may be indexed on the basis of the face cantered cubic structure of magnetite. A comparison of XRD spectrum of synthesized magnetite nanoparticles (Fe_3O_4NPS) with the standard XRD data for bulk magnetite (JCPDS file No. 19-0629) confirmed that the magnetite particles formed in our experiments were in the form of nanocrystals, as evidenced by the peaks at 2θ values of 18.43^o, 30.77^o, 36.42^o,43.48^o, 54.55^o, 56.78^o and 62.28^o corresponding to (111), (220), (311), (222), (400), (422) and (511) Bragg's reflections, respectively, **Figure 3**, which may be indexed based on the face centered cubic (fcc) structures of magnetite. The X-ray diffraction results clearly show that the magnetite nanoparticles formed by our green method in presence of *U. tomsentos* leaf extract are crystalline in nature.

It was found that the average size from XRD data and using Debye-Scherer equation was approximately 12 nm. The presence of structural peaks in XRD patterns and average crystalline size around 12 nm clearly illustrates that magnetite particles synthesized by our green method were nano-crystalline in nature. The average particle size of magnetite nanoparticles calculated using Debye-Scherrer equation (Salem et al., **2**013):

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

Where D is the mean diameter of nanoparticles, β is the full width at half-maximum value of XRD diffraction lines, λ is the wavelength of X-ray radiation source 0.15405 nm, θ is the half diffraction angle –Bragg angle and K is the Scherrer constant with value from 0.9 to 1. The presence of structural peaks in XRD patterns and average crystalline size calculated 12 nm clearly illustrates the magnetite synthesized were nanocrystalline in nature.

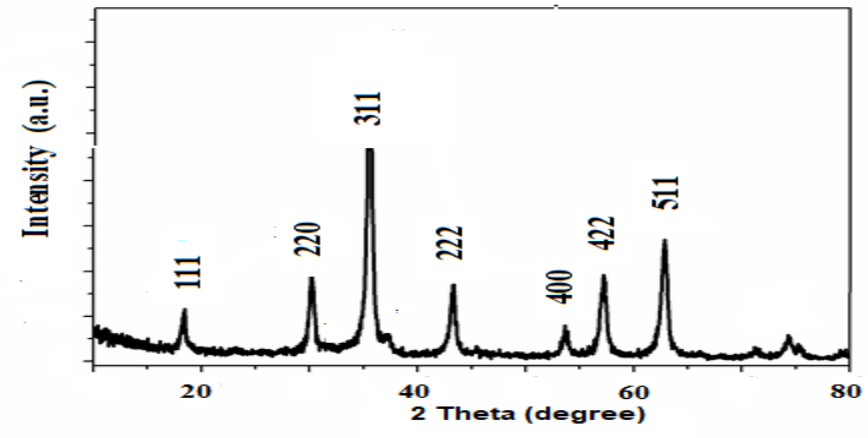

Figure 3. XRD pattern of synthesized magnetite nanoparticles

3.3. Fourier transforms infrared spectroscopy analysis

FT-IR spectra of *U. tomensota* leaves extract is shown in **Figure 4.** The *U. tomensota* leaves extract displays a number of absorption peaks, reflecting its complex nature. Peak at 3383 cm^{-1} results are due to the stretching of -OH groups of alcohol and phenol compounds. The strong absorption peaks at 2924 cm^{-1} and 2850 cm^{-1} could be assigned to –CH stretching vibrations of $–CH_3$ and $–CH_2$ functional groups in aliphatic and aromatic compounds. The shoulder peak at 1739 cm^{-1} and strong peak at 1612 cm^{-1} indicated the fingerprint region of C=O and N–H groups in amide (I) and amide (II) of protein. The intense band at 1442 cm^{-1} and 1230 cm^{-1} can be assigned to the C-N stretching vibrations of aliphatic amines. The peak at 1064 cm^{-1} may be attributed to C-O-C stretching mode of aromatic ether linkage group. The peak at 621 cm^{-1} indicates the –OH bending of the phenolic groups. FTIR study indicated that the free hydroxyl (-OH), carboxyl (-C=O), C-N and amine (N- H) groups present in the structure of *U. tomensota* leaves extract are mainly involved directly in synthesis of magnetite nanoparticles, **Figure 5.**

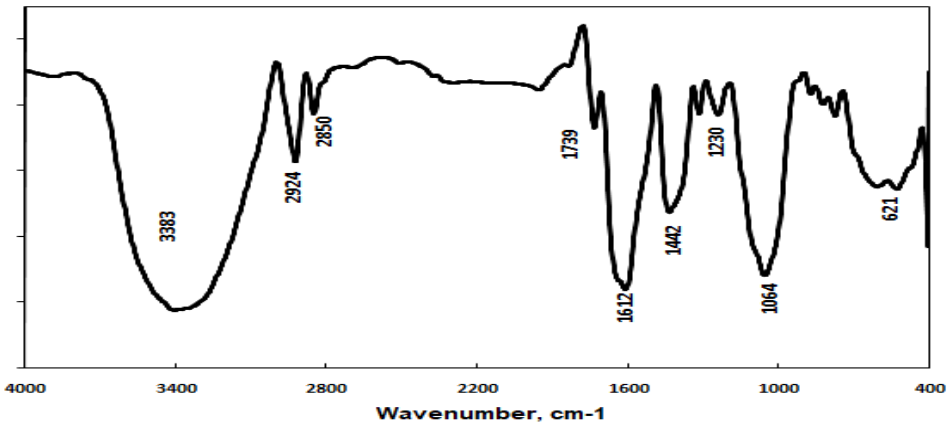

Figure 4. FT-IR spectrum of U. *tomensota* leaves extract

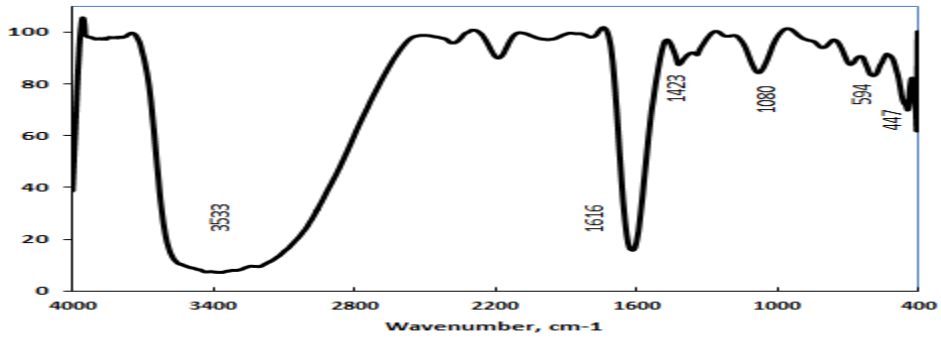

Figure 5. FT-IR of synthesized magnetite nanoparticles

3.4. Transmission electron microscopy (TEM) images

The morphology of magnetite nanoparticles was revealed by TEM technique. TEM image of green synthesized Fe_3O_4NPs showed that magnetite nanoparticles were in spherical shape, Figure6. Besides, a histogram of particle size distribution was drawn according to the size of 20 nanoparticles, Figure7. The average particle size was 20 nm with the standard deviation of 2 nm. The crystallite size of the synthesized Fe_3O_4NPs was found to be 18.8 nm from XRD analysis, which is in an agreement with the result obtained from the TEM that shows a size distribution between 11.0 and 20.0 nm. A few very small spherical objects can be observed from the image which might be due to the residue of *U. tomensota.*

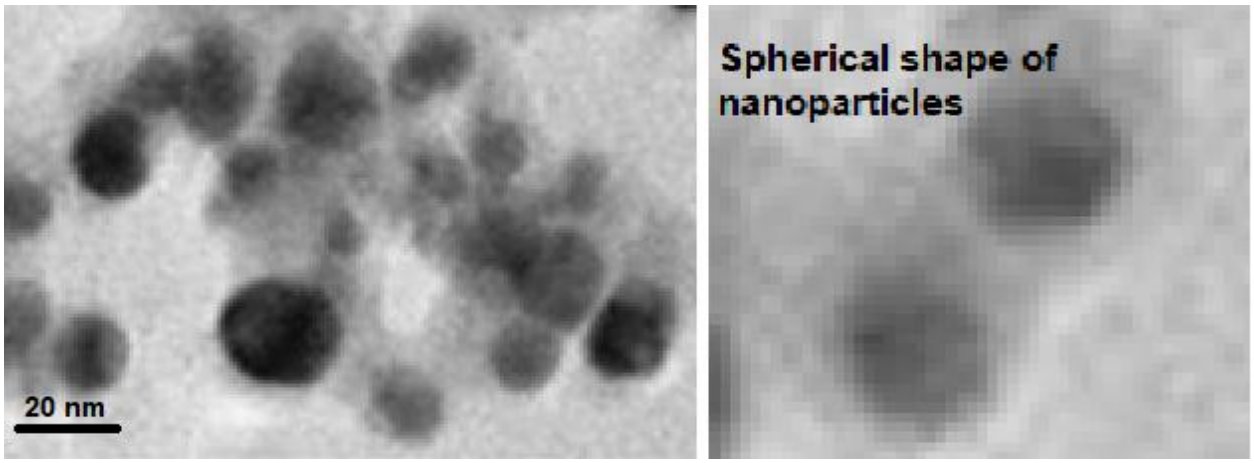

Figure 6. TEM images of synthesized magnetite nanoparticles

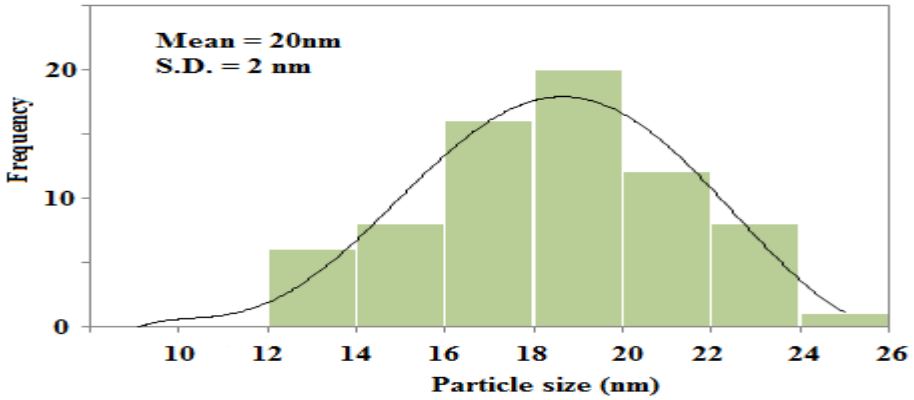

Figure 7. Histogram of particle size distribution of synthesized magnetite nanoparticles

3.5. Aphicidal effect of magnetite (Fe_3O_4 NPs) on the green peach aphid:

Toxicity was assessed through mortality percents and the data analysis for toxicity against early and late nymph instars constructed in Tables 1 and 2, respectively to compare between different concentrations of magnetite NPs used in bioassay experiments. On the both stage groups of GPA, the results showed increasing in mortality % with increase in concentrations and through time periods. For instance higher concentration (1000 ppm) showing higher mortality against both early (55%) and late (44%) nymphal instars after 24h compared with the other concentrations at the same period Tables 1 and 2. These percent of mortality increased with time to 86.2 and 73.8 for early and late stages, respectively after 72hr of treatment. There were significant differences among concentrations on their effects on the two categories of the GPA based on one way ANOVA analysis and LSD means separation. The means difference of (Fe_3O_4) NPs concentrations against early and late nymphal instars of the GPA were significant. Significantly levels were (0.13) and (0.037) for early and late instars, respectively **.**Also, mortality % of both categories of aphid treated with all concentrations were significantly higher than the two controls treatment. The effect of all concentrations against early and late nymphal instars were higher than the aqueous extract effect as represented in Tables (1 and 2) which means that the mortality of GPA was due to magnetite NPs effect rather than the extract effect. Plant extract effect was closely to control effect and had no significant differences in their effect either on early or late nymph instars of GPA.

Table 1: Means of mortality percent (%) of early nymphal instars of the green peach aphid by different concentrations of magnetite (Fe_3O_4NPs) with time passing under lab conditions

Concentrations (ppm)	Mortality percent		
	24h	48h	72h
50	22.60 ^{b} ± 0.68	30.80 ^{b} ± 0.71	37.00 ^{b} ±0.78
100	27.00 ^{b} ± 0.55	34.80^{b} ± 0.48	42.00 ^{bc} ± 1.14
200	32.80 ^{c} ± 0.92	43.20^{c} ± 1.44	48.20 ^{c} ± 0.99
400	37.80 ^{c} ±0.88	47.60^{c} ± 0.52	56.60^{d} ± 0.94
600	48.60 ^{d} ± 0.94	57.40 ^{d} ± 0.79	68.00 ^{e} ± 0.88
800	51.20 ^{de} ± 1.31	62.20^{de} ± 2.44	76.00 ^{f} ± 2.13
1000	55.00 ^{e} ± 0.82	76.80 ^{e} ± 2.23	86.20 ^{g}± 2.68
C*	2.6 ^{a} ± 0.54	5.00 ^{a} ± 0.98	6.40 ^{a} ± 1.47
C1**	2.4 ^{a}± 0.66	3.70 ^{a} ± 0.68	5.60 ^{a} ± 0.78

Means in the same column sharing the same small letter did not differ significantly using LSD test at 5% probability level.

C*: is the control No 1; using water alone.

C1** : the control No 2; using the aqueous extract alone.

Table.2: Means of mortality percent (%) of late nymph instars of the green peach aphid by different concentrations of Fe_3O_4NPs under lab conditions.

Concentration (ppm)	Mortality percent		
	24h	48h	72h
50	12.60 b ± 0.67	21.40 b± 1.030	25.80b ± .735
100	16.60 c ± 0.42	24.80 c± 490	29.60 c ± .980
200	23.20 d ± 0 .76	31.40 d± .678	36.20 d ± .735
400	27.40 e± 0.75	36.60 e± .245	45.40 e± .678
600	37.60 f± 0.56	46.00 f± .837	55.60 f± .600
800	40.40 g ± 1.03	53.40 g± 1.833	62.60 g± 1.887
1000	44.00 h ± 1.09	66.00 h± 2.098	73.80 h± 2.458
C*	3.2 a ± 1.24	5.00 a ± 1.09	6.20 a ± 1.48
C1**	2.9 a ± .66	5.20 a ± 0.58	6.80 a ± 0.95

Means in the same column sharing the same small letter did not differ significantly using LSD test at 5% probability level.
C*: is the control No 1; using water alone.
C1**: the control No 2; using the aqueous extract alone.

Conclusion

In the present work, we first report an eco-friendly and simple method for synthesis of magnetite nanoparticles (Fe_3O_4) using *U. tomentosa* leaves aqueous extract. FTIR analysis of aqueous *U. tomentosa* extract indicated the presence of phyto-constituents such as amines, aldehydes, phenols, and alcohols, which were the surface active molecules stabilized the magnetite nanoparticles. XRD analysis reveals that the average size of the nanoparticles was found to be 20 nm which was calculated by Debye-Scherrer equation. FT-IR and XRD results corroborated the purity of the synthesized Fe_3O_4NPs. Green synthesized Fe_3O_4NPs was evaluated against green peach aphid showing a significant effective activity. The method of the present study offers several important advantageous features. First, the synthesis route is economical and environmentally friendly, because it involves inexpensive and non-toxic materials, and large scale synthesis.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of this manuscript

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