Original Article

Evaluation of the physical properties of fluorescent carbon nanodots synthesized using Nerium oleander extracts by microwave-assisted synthesis methods

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ABSTRACT

Rapid and one-step green synthesis of carbon nanodots (CDs) from Nerium oleander leaves was accomplished via domestic microwave oven and microwave-assisted hydrothermal synthesizer under various physical conditions. Effects of the synthesizer system, extract type depending on the solvents used in plant extraction, and synthesis conditions; such as reaction time, reaction temperature, surface passivation agent inclusion into the reaction medium, on the physicochemical properties and optical feature of CDs were investigated. The impacts of relevant conditions on CDs feature were determined clearly via UV–visible spectrophotometry, fluorescence spectrophotometry, dynamic light scattering analysis, and Fourier transform infrared spectroscopy. According to the results, while the most effective parameter on the fluorescence feature of CDs was determined as the presence of surface passivation agent (polyethylene glycol, PEG), the alteration in the fluorescence intensity depending on the reaction time and the reaction temperature was also observed. It was reported that the synthesis system and PEG existence in the reaction medium were more effective than the other inspected parameters on the hydrodynamic particle size, in general. Under optimum conditions, nanoparticles with a hydrodynamic size of less than 5 nm were obtained. The surface zeta potential charges of all particles were found as negative. While the extract type was significantly effective on the surface zeta potential of CDs synthesized by domestic microwave oven, the reaction temperature was found to be significant for the ones synthesized via microwave-assisted hydrothermal synthesis.

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1. Introduction

Carbon nanoparticle studies have been gaining popularity since their accidental exploration in 2004 [1]. Carbon nanodots (CDs) applications in bio-imaging, drug delivery, solar cells, photodetectors and etc. become prevalent because of their unique properties such as optic features, mechanical strength, thermal and electrical conductivity, and etc. [2–11]. Even though CDs can be synthesized by various methods; in the early stage of this scientific invention, laser ablation [12,13], electro-oxidation [14–16] or oxidative acid treatment [17,18] had been used for the synthesis. Fortunately, easier, cheaper, fast and also proper for large-scale production methodologies have been developed as hydrothermal [19–21], microwave/microwave assisted [22–32] and ultrasound [33] synthesis. As the microwave-assisted synthesis of CDs can be executed by using domestic microwave oven (MWO), it can be also performed by microwave-assisted hydrothermal (MAH) synthesis which is the combination of hydrothermal and microwave methods in a high pressure-sealed reaction vessel [24]. By virtue of these novel techniques, utilization of natural products as carbon source became popular. Although nanoparticles arising from natural materials were reported widely for years [34–36], plant-based carbon nanoparticle synthesis has been studying recently [19,37–43].

Nerium oleander (Oleander), an evergreen, toxic shrub plant is one of the members of the Apocynaceae family. Long narrow green leaves are characteristic for this species, and its flowers are commonly white or pink. Nerium oleander has a wide range of chemical constituents such as cardiac glycosides, cardenolides, pregnanes, triterpenes, polyphenols, flavonoid glycosides and etc. [44–49]. For the synthesis of CDs from natural sources, the saccharide content of the reaction media is important due to the utilization of saccharides and their derivatives as carbon sources. Therefore, the chemical composition of natural extracts is also a crucial significance. As is known, the solvents used in the extraction step can change the chemical contents of the extracts dramatically.

For Oleander, while aqueous extracts of their leaves contain sterols, flavonoids, terpenoids and etc., these compounds are not situated in ethanol extracts. But, in contrast, cardiac glycosides and saponins appear in ethanol extracts [50]. Besides, 2.3% of Oleander aqueous leaf extract is crude polysaccharides like arabinose, galacturonic acid, galactose and rhamnose [45]. Therefore, Oleander can be an appropriate candidate for CDs synthesis, and the investigation of the effects of the different solvent extracts of its leaves can give remarkable results. Even, microwave/microwave assisted methods are used for CDs synthesis, also using these techniques combining with the other synthesis methods for photoluminescence (PL) enhancement of CDs have been reported [51–53]. In this original paper, the effects of the type of microwave synthesis methods (either conventional or hydrothermal) and synthesis conditions on the physicochemical properties of CDs were investigated. The results of the present study showed that the method of microwave-based synthesis reveals a significant change in particle size, surface properties, and PL characteristics.

2. Experimental studies

2.1. Materials and methods

2.1.1. Plant material

Nerium oleander leaves were collected from Esenler, Istanbul (41°01’37.7"N, 28°53’32.1"E) at 82 m in May 2016 was booked in Izmir, Ege University Faculty of Pharmacy Herbarium (IZEF) with number 6056.

2.1.2. Chemicals and equipment

Ethanol and polyethylene glycol (PEG) 10000N were purchased from Sigma-Aldrich. Elma, TI-H 5 ultrasonic bath was used during the extraction process. Microwave syntheses were accomplished at Arcelik MD 565 S domestic microwave oven and Mars (CEM) microwave assisted hydrothermal synthesizer. Characterization studies of CDs were performed using Shimadzu UV-1800 UV-Vis spectrophotometer, Agilent Cary Eclipse fluorescence spectrophotometer, Malvern Zeta Sizer Nano ZS, and Perkin Elmer Frontier FT-IR.

2.2. Preparation of plant extracts

Oleander fresh leaves were collected from nature and cleaned up by distilled water three times. An oven at 70 °C was used to dry the leaves and after two days from the drying period, leaves were ground to enhance their surface areas. Two different solvent extracts of Oleander leaves were prepared in an ultrasonic bath at room temperature for 5 h with ultra-pure water and ethanol at the concentration of 12.5 g leaves/100 mL solvent for each. At the final step of the extraction procedure, extracts were centrifuged at 5000 rpm for 15 min to remove solid parts and clear extracts were kept at +4 °C.

2.3. Microwave-assisted synthesis of CDs

2.3.1. Synthesis using microwave oven

For the synthesis of CDs via domestic microwave oven, a kitchen type microwave oven with 800 W output power was used. Ethanol and aqueous extracts of N. oleander were utilized as carbon sources for CDs synthesis, separately. For the synthesis of CDs by using Oleander ethanol extract as the carbon source, 1 mL ethanol extract and 1 mL ultra-pure water were added to the ceramic crucibles. Similarly, for the synthesis of CDs by using aqueous extract, 1 mL aqueous extract and 1 mL ethanol were added to the ceramic crucibles. To investigate the effect of surface passivation agent existence in the reaction medium on CDs feature, 1 g PEG 10000N was added to the some of the formulations and blended in the ceramic crucibles containing 1 mL extract and 1 mL ethanol or ultra-pure water until all ingredients completely dissolved (Table 1). According to the extract types and PEG existence in the reaction medium, subscripts E, W and PEG were used after ‘CD’ term for ethanol, water, and polyethylene glycol 10000N, respectively.

For the CDs synthesis via MWO, ceramic crucibles containing reaction medium were placed at MWO with 800 W output power for 5, 15 and 40 min, respectively. After the synthesis step, each residue in the crucibles was scratch and dissolved in
Table 1 – Formulation of reaction media.

<table>
<thead>
<tr>
<th>Carbon nanodots</th>
<th>EtOH extract of Oleander</th>
<th>H₂O extract of Oleander</th>
<th>Ethanol</th>
<th>Ultra-pure water</th>
<th>PEG 10000N</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDₑ</td>
<td>1 mL</td>
<td>–</td>
<td>–</td>
<td>2 mL</td>
<td>–</td>
</tr>
<tr>
<td>CDₑ@PEG</td>
<td>1 mL</td>
<td>–</td>
<td>–</td>
<td>2 mL</td>
<td>1 g</td>
</tr>
<tr>
<td>CDₜ</td>
<td>–</td>
<td>1 mL</td>
<td>1 mL</td>
<td>1 mL</td>
<td>–</td>
</tr>
<tr>
<td>CDₜ@PEG</td>
<td>–</td>
<td>1 mL</td>
<td>1 mL</td>
<td>1 mL</td>
<td>1 g</td>
</tr>
</tbody>
</table>

Fig. 1 – Schematic view of the experimental procedure.

6 mL ultra-pure water and centrifuged for 20 min at 6000 rpm and 13,500 rpm, respectively, to obtain clear solutions. The supernatants were collected and stored at +4 °C. For the characterization studies, 50 μL of these clear solutions diluted in 3 mL ultra-pure water. A brief schematic representation of the experimental part is placed in Fig. 1.

2.3.2. Synthesis using microwave-assisted hydrothermal synthesizer

The MAH synthesis of CDs was fulfilled in a Mars (CEM) microwave synthesizer at 200 and 250 °C with a temperature ramp change period for 15 min and reaction time for 15 min. Reaction media for CDs synthesis were prepared as mentioned in Section 2.3.1, and the formulations were transferred to the hydrothermal reactor made up of Teflon. After the synthesis step, each residue was dissolved in 6 mL ultra-pure water and centrifuged for 20 min at 6000 rpm and 13,500 rpm, respectively, to obtain clear solutions. The supernatants were collected and stored at +4 °C. For the characterization studies, 50 μL of these clear solutions diluted in 3 mL ultra-pure water.

2.4. Characterization studies

Photoluminescence spectroscopy (Agilent Cary Eclipse) was conducted for optical characterization and the UV absorption spectra of CDs were recorded on a UV-spectrophotometer (Shimadzu UV-1800) using a 1 cm path length cuvette [54]. Additionally, fluorescence emitted from CDs was visualized with a UV lamp at 365 nm wavelength. Particle size distribution and surface zeta potential of CDs synthesized were measured with dynamic light scattering (DLS) technique (Malvern Zetasizer Nano-ZS). A clear disposable zeta cell was used for particle size distribution, and approximately 1 mL of CD solution was taken in it. Measurements were made in three replicates each with 12 zeta runs and mean particle size and standard deviations were determined. Approximately 1 mL of CD solution was taken in a clear disposable zeta cell in the same way as the size measurement for surface zeta potential measurement. Three rounds of measurements each with 20 zeta runs were performed for analysis with dip cell. The Fourier-transform infrared (FT-IR) spectrum of CDs with a resolution of 4 cm⁻¹ was collected over the range of 450–4000 cm⁻¹ on an FT-IR spectrometer (Perkin Elmer Frontier FT-IR). All measurements were conducted in ambient atmosphere and room temperature.

3. Results and discussion

3.1. Photoluminescence of CDs

Fluorescence feature of CDs was observed and photographed under 365 nm UV light (Fig. 2), and the fluorescence intensity values were investigated at 365 nm excitation by fluorescence spectroscopy (Fig. 3). The PL enhancement due to polyethylene glycol as a surface passivation agent was verified with the clear observation of higher fluorescence emission obtained from PEG included formulations of CDs (Fig. 3) [65–57]. In MWO based synthesis, the highest PL intensities for CDₑ@PEG and CDₜ@PEG was achieved once after 40 min of reaction at 800 W output power. Furthermore, it was observed that the maximum emission peaks (λₑ) of these CDₑ@PEG and CDₜ@PEG were red-shifted (Figs. 2a and 3b). This red-shifted PL emission of CDs could be attributed to a oxygenated surface revealing narrower energy levels and increased surface defects, thereof [58]. At shorter synthesis periods as 5 and 15 min in MWO, no PL was observed from CDs synthesized (Figs. 2a, 3a and b) which shows that the shorter time operation times below 40 min, carbonization was not sufficient and contribution of PEG as surface passivation agent was not occurred yet [59].

For CDs synthesized via MAH system, the highest PL intensities were achieved at 250 °C after 15 min (Figs. 2b and 3d). While the PL values for CDₜ@PEG at both 200 and 250 °C were similar, a dramatic increase was observed at 250 °C for CDₑ@PEG (Fig. 3c and d). This case could be explained by the insufficient carbonization ratio of the contents of ethanol extract of
Fig. 2 – Fluorescence feature of particles under 365 nm UV light. (a) Domestic microwave oven and (b) microwave-assisted hydrothermal system.

Fig. 3 – Fluorescence spectra of CDs. (a and b) Domestic microwave synthesis and (c and d) microwave-assisted hydrothermal system (*The intensity peak of CD in Fig. 1a situates under the peak of CD@PEG*).
Fig. 4 – Absorbance spectra of CDs. (a and b) Domestic microwave synthesis and (c and d) microwave-assisted hydrothermal system.

Oleander at this temperature [59]. Eventually, comparison of both microwave-based systems by the final PL intensities of the CDs clearly showed that MWO-based synthesis is a better alternative to generate CDs with enhanced PL.

3.2. UV–vis spectra of CDs

Fig. 4 presents the absorbance spectra of carbon dots at certain concentrations (12 mg/mL). The peaks observed in the range of 300–400 nm can be associated with the n–π* transition of C=O [60–62]. The peaks between 240 and 300 nm can be related to the π–π* transition of aromatic units [6,63,64]. These peaks at the range of 240–300 nm and 300–400 nm were observed at all CDs studied. Strong absorption peaks at ~230 nm and ~290 nm were connected with the π–π* transition of the non-bonding electrons [54]. Absorbance increases in CDs synthesized by MWO were observed at CD_{E}\text{PEG} and CD_{W}\text{PEG} after 40 min while the same behavior was observed in MAH synthesis. These increases at around 370 nm can be associated with the increase of surface energy levels in CDs [65].

3.3. Measurement of hydrodynamic size and surface zeta potential

Hydrodynamic particle size (R_h) and surface zeta potential (ζ-Pot) data presented by means of changing parameters were shown in Table 2.

For CDs synthesized via MWO method, R_h of most of the particles was reported as smaller than 100 nm while aqueous extract based CDs were stated as the smallest ones with 2.27 ± 0.226 nm (Fig. 5a). This case may be related to the chemical composition of aqueous extract. In which extract expected to be richer in water-soluble polysaccharide and/or its derivatives as compared to the ethanol extract due to polarity difference of the both solvents. Besides, presence of polysaccharides may enhance the surface passivation and may induce the formation of smaller particles.

As for CDs synthesized via MAH method, R_h of the particles were reported in the range of 2.66–825 nm (Fig. 5b). When the data evaluated, the impact of PEG existence in the reaction medium was clearly observed. CDs synthesized from PEG included formulations were found as extremely smaller than PEG-free formulations (Fig. 5b). The effect of surface passivation agent on the size of particles was found compatible with the previous report performed by Sonthanasamy et al. [55]. However, as can be seen from Fig. 5b, no significant relationship between synthesis temperature and size was determined.

ζ-Pot measurements showed that all CDs synthesized had negatively charged surface regardless of the operation parameters evaluated and changed in the range of −8.9 and −28.3 mV (Table 2). There is no clear relation between surface potential and synthesis conditions for MWO synthesis of CDs. The only noticeable difference between surface potential data is PEG included CDs synthesized from aqueous extract showing more
<table>
<thead>
<tr>
<th>Method</th>
<th>Sample</th>
<th>Hydrodynamic particle size (R_h) ± Std. Dev. (nm)</th>
<th>Average surface zeta potential (ζ-Pot) ± Std. Dev. (mV)</th>
<th>Conductivity (mS/cm)</th>
<th>Mob (μmcm/V s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Synthesis via</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>domestic microwave</strong></td>
<td>CD_E Synt. period: 5 min</td>
<td>64.77 ± 9.735</td>
<td>−28.3 ± 5.8</td>
<td>0.0112</td>
<td>−2.217</td>
</tr>
<tr>
<td></td>
<td>CD_E@PEG Synt. period: 5 min</td>
<td>108.12 ± 5.603</td>
<td>−12.3 ± 0.473</td>
<td>0.0268</td>
<td>−0.962</td>
</tr>
<tr>
<td></td>
<td>CD_W Synt. period: 5 min</td>
<td>15.46 ± 2.253</td>
<td>−20.6 ± 6.09</td>
<td>0.0256</td>
<td>−1.611</td>
</tr>
<tr>
<td></td>
<td>CD_W@PEG Synt. period: 5 min</td>
<td>2.27 ± 0.226</td>
<td>−14 ± 3.06</td>
<td>0.0375</td>
<td>−1.099</td>
</tr>
<tr>
<td></td>
<td>CD_E@PEG Synt. period: 15 min</td>
<td>172.28 ± 7.651</td>
<td>−16.1 ± 1.153</td>
<td>0.0234</td>
<td>−1.263</td>
</tr>
<tr>
<td></td>
<td>CD_W@PEG Synt. period: 15 min</td>
<td>2.66 ± 0.227</td>
<td>−22.37 ± 1.358</td>
<td>0.0338</td>
<td>−1.752</td>
</tr>
<tr>
<td></td>
<td>CD_W@PEG Synt. period: 40 min</td>
<td>3.38 ± 0.338</td>
<td>−11.4 ± 3.2</td>
<td>0.0023</td>
<td>−0.8936</td>
</tr>
<tr>
<td><strong>Synthesis via</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>microwave-assisted</strong></td>
<td>CD_E Synt. temp.: 200 °C</td>
<td>288.41 ± 29.637</td>
<td>−11 ± 2.32</td>
<td>0.0864</td>
<td>−0.8656</td>
</tr>
<tr>
<td><strong>hydrothermal-assisted</strong></td>
<td>CD_E@PEG Synt. temp.: 200 °C</td>
<td>5.7 ± 0.587</td>
<td>−13.4 ± 1.04</td>
<td>0.0622</td>
<td>−1.053</td>
</tr>
<tr>
<td><strong>synthesizer</strong></td>
<td>CD_W Synt. temp.: 200 °C</td>
<td>615.99 ± 47.218</td>
<td>−14.8 ± 3.04</td>
<td>0.101</td>
<td>−1.163</td>
</tr>
<tr>
<td></td>
<td>CD_W@PEG Synt. temp.: 200 °C</td>
<td>2.8 ± 0.256</td>
<td>−14.63 ± 3.5</td>
<td>0.0909</td>
<td>−1.146</td>
</tr>
<tr>
<td></td>
<td>CD_E@PEG Synt. temp.: 250 °C</td>
<td>370.45 ± 45.117</td>
<td>−8.9 ± 1.598</td>
<td>0.033</td>
<td>−0.698</td>
</tr>
<tr>
<td></td>
<td>CD_W@PEG Synt. temp.: 250 °C</td>
<td>2.66 ± 0.25</td>
<td>−9.67 ± 0.749</td>
<td>0.0984</td>
<td>−0.7567</td>
</tr>
<tr>
<td></td>
<td>CD_W@PEG Synt. temp.: 250 °C</td>
<td>825.01 ± 72.125</td>
<td>−13.87 ± 1.168</td>
<td>0.0466</td>
<td>−1.087</td>
</tr>
<tr>
<td></td>
<td>CD_W@PEG Synt. temp.: 250 °C</td>
<td>4.9 ± 0.589</td>
<td>−8.48 ± 2.185</td>
<td>0.0875</td>
<td>−0.664</td>
</tr>
</tbody>
</table>
negative charges than the ethanol extract based ones which also supports the narrow size distribution of those CDs. When the passivation agent was not included, a more negative surface net charge was obtained due to a more acidic –COOH rich particle surface (Fig. 6a). For MAH synthesis of CDs, a recognizable decrease on the negativity of the particles’ surface potential was observed with ascending synthesis temperature as from −11 to −8.9, −14.8 to −13.9, −13.4 to −9.7 and −14.6 to −8.5 mV for CD$_E$, CD$_W$, CD$_{E@PEG}$, and CD$_{W@PEG}$, respectively (Fig. 6b).

### 3.4. Surface properties by FT-IR

The changes in the surface functional groups depending on the reaction conditions were investigated by FT-IR spectrometer. For CDs synthesized by MWO, while the general profiles of FT-IR spectra were quite similar to each other, only CDs synthesized for 5 min showed different profiles (Fig. 7). While for CD$_{E@PEG}$ and CD$_{W@PEG}$ with 5 min synthesis period in MWO, O–H/N–H stretching peaks were identified at ~3660 cm$^{-1}$, these peaks disappeared with the increased operation times (Fig. 7b). The disappearance of free –OH peak around 3600 cm$^{-1}$ for CDs with 15 and 40 min synthesis period in MWO, can be explained by decreased number of –OH groups by domination of other functional groups instead. Moreover, broad H bonded –OH stretching vibrations were specified at around 3260 cm$^{-1}$ for CD$_{E@PEG}$ and CD$_{W@PEG}$ synthesized via MWO for 15 and 40 min, and these peaks may be attributed to intermolecular hydrogen bonding in CDs [2,39,66–68]. Aliphatic C–H stretching bands between 2880 and 2980 cm$^{-1}$ were observed for most of the CDs [2,66,69]. Nevertheless, the peaks at around 1383 and 1370 cm$^{-1}$ were only observed at CDs with 5 min synthesis period in MWO, and these peaks were attributed to CH$_3$ bending vibrations [69]. Unlike CDs obtained via MAH synthesis, sharp peaks observed at ~1740 cm$^{-1}$ and ~1630 cm$^{-1}$ were indicated with C=O stretching and C=C bending, respectively, for all of the CDs synthesized by MWO (Fig. 7a and b) [2,39,66–70]. While strong C=O stretching at around 1740 cm$^{-1}$ can be observed in CDs with 5 min synthesis period, this peak disappeared with the ascending synthesis period and C=C benders were observed in place of this peak. Additionally, C=C bending at 1630 cm$^{-1}$ may be associated with the aromatic structures in CDs by combining the UV–vis data which was indicated with the π–π$^*$ transition at around 260 nm (Figs. 4 and 7b) for CD$_{E@PEG}$ and CD$_{W@PEG}$ synthesized via MWO for 15 and 40 min [39,71]. Also, the stretching vibrations at between 3000 and 3020 cm$^{-1}$ were related to the aromatic C–H stretching bands [2,66].
Fig. 7 – FT-IR spectra of CDs. (a and b) Domestic microwave synthesis and (c and d) microwave-assisted hydrothermal system.

For CDs synthesized via MAH, O–H/N–H stretching peak was identified at ~3660 cm⁻¹ for only CD_{W@PEG} synthesized at 250 °C (Fig. 7d) [2,39,66–68]. Similarly, broad H bonded –OH stretching vibrations at around 3260 cm⁻¹ which were attributed to intermolecular hydrogen bonding in CDs were observed for only CD_{W} with 250 °C synthesis temperature (Fig. 7d) [2,39,66–68]. As in CDs synthesized via MWO, aliphatic C–H stretching bands between 2880 and 2980 cm⁻¹ were
observed for most of CDs synthesized by MAH synthesizer (Fig. 7c and d) [2,66,69]. Weak CH2 bending vibrations were identified at around 1383 and 1370 cm\(^{-1}\) for CD\(_E\) and CD\(_{W@PEG}\) with synthesis temperature 250 and 200 ˚C, respectively [69]. Weak stretching bands observed for CDs synthesized at 250 ˚C at around 1040, 1160 and 1250 cm\(^{-1}\) were attributed to C–O vibrations (Fig. 7d). Also, vibrations at \(~1040\) cm\(^{-1}\) may be related with C–O stretch of carboxylic (–COOH) group [2,39,66,69,71]. As for the stretching vibrations at 957 cm\(^{-1}\), they may be associated with C–OH stretchings in epoxy groups (Fig. 7c and d) [66]. These results showed that in both systems the final surface functional groups were affected by the time-period of energy given to the system and in each system resulting functional groups differentiated depending on the extract type used.

4. Conclusions

Herein, the application of two microwave based methods for one-step synthesis of CDs were demonstrated; and the impacts of the system, extract type, reaction medium, and reaction conditions were determined clearly. The main findings were summarized as follows:

- Reaction period was found as critically significant on the fluorescence feature of CDs synthesized using MWO. Both CD\(_{E@PEG}\) and CD\(_{W@PEG}\), the optimum time for synthesis process was found to be 40 min which resulted in almost 10 times higher PL values.
- For CD\(_{E@PEG}\) synthesized via MWO, the hydrodynamic sizes of the particles were varied from 108 nm to 47 nm for 5 and 40 min, respectively.
- The dramatic effect of the surface passivation agent on the particle size was reported for MAH synthesis while the hydrodynamic size range of CD\(_E\) and CD\(_W\) was between 288 and 825 nm, this range decreased to 2.6 and 5.7 nm for CD\(_{E@PEG}\) and CD\(_{W@PEG}\).
- For MAH synthesis of CDs, a recognizable decrease on the negativity of the particles’ surface potential was observed with ascending synthesis temperature as from \(-11\) to \(-8.9, -14.8\) to \(-13.9, -13.4\) to \(-9.7\) and \(-14.6\) to \(-8.5\) mV for CD\(_E\), CD\(_W\), CD\(_{E@PEG}\), and CD\(_{W@PEG}\), respectively.
- Although, the chemistry and fluorescence features of CDs synthesized by MWO were similar in general for both solvent extracts of Oleander, the hydrodynamic particle size and the surface potential of CDs were varied depending on the extract types due to variations of the extract contents.
- When two microwave-based synthesis methods were compared, MWO synthesis was determined as a better alternative to generating photoluminescence enhancement on CDs. However, the opportunity of CDs synthesis at really short reaction times via MAH synthesis is undeniable.

The results of the present study add piece of new insight to the PL mechanism of CDs prepared from two different extracts (aqueous and ethanol) of \(N.\) oleander and provide an effective strategy for preparation CDs with two microwave based synthesis routes for their further use in different applications including, catalysis, drug delivery and imaging.

Conflicts of interest

The authors declare no conflicts of interest.

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