Electronic Supplementary Material (ESI) for RSC Advances.

Supporting information

Effect of heteroatoms on optical properties and enzymatic activity of N-doped carbon dots

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Transmission electron microscopy (TEM) images of N-CDs

The morphology of non-doped **CD** and **N-CD**s were investigated by TEM (H-7650 Hitachi, Japan) installed in the Center for University-wide Research Facilities (CURF) at Jeonbuk National University. The average size of each nanoparticle was calculated by measuring the diameters of 200 particles in TEM images (Figure S2).

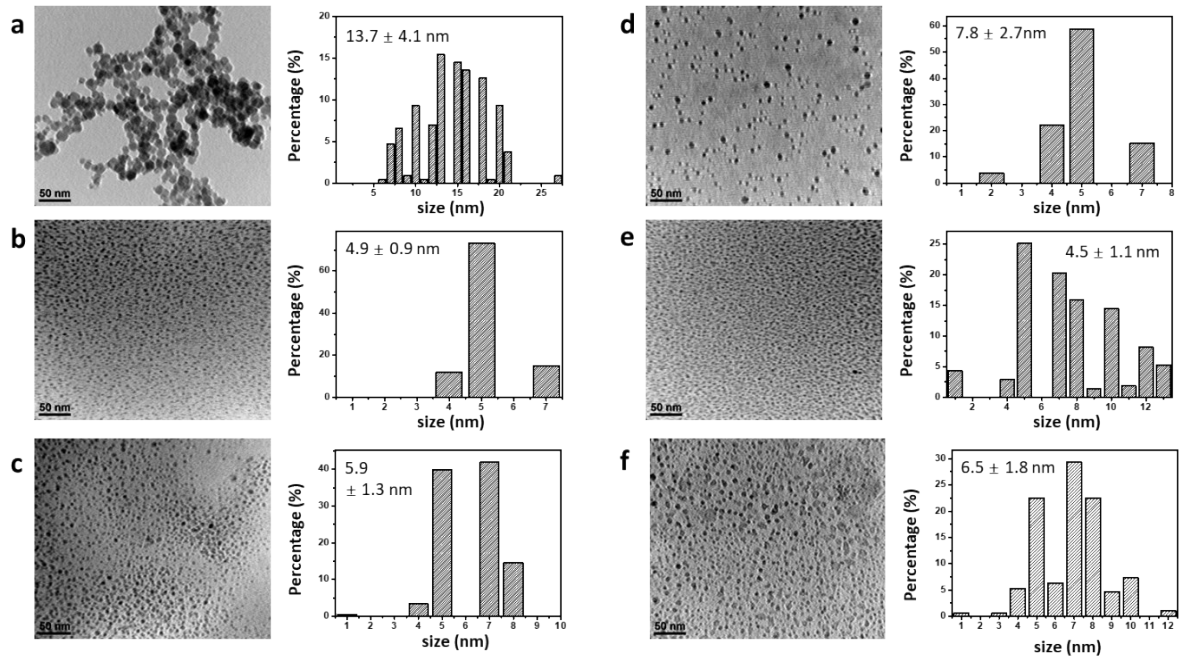

Figure S1. TEM images and particle size distribution histograms of non-doped **CD** and **N-CD**s; a) **N-CD_1**, b) **N-CD_2**, c) **N-CD_3**, d) **N-CD_4**, e) **N-CD_5**, and f) non-doped **CD**.

High resolution (HR)-TEM image of non-doped CD

Non-doped **CD** possesses a crystalline structure with a lattice distance of 0.2 nm, which matches with the (100) plane of graphite.

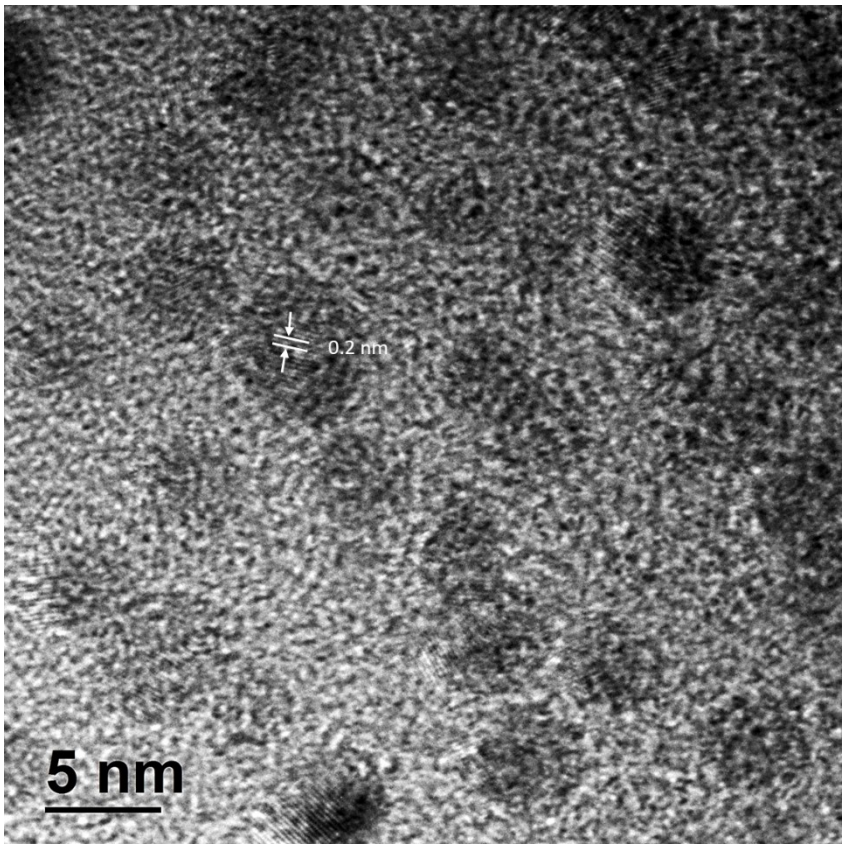

Figure S2. HR-TEM image of non-doped **CD**.

Analysis of crystal structure of obtained N-CDs and non-doped CDs

The X-ray diffraction (XRD) pattern was obtained using Miniflex Benchtop X-ray diffractometer (Rigaku). XRD spectrum of all **N-CD**s shows broad peaks, indicating their amorphous nature while that of non-doped **CD** reveals the crystalline character of non-doped **CD**. The incorporation of the N atom into the carbogenic domains leads to the amorphous nature of **N-CD**s.

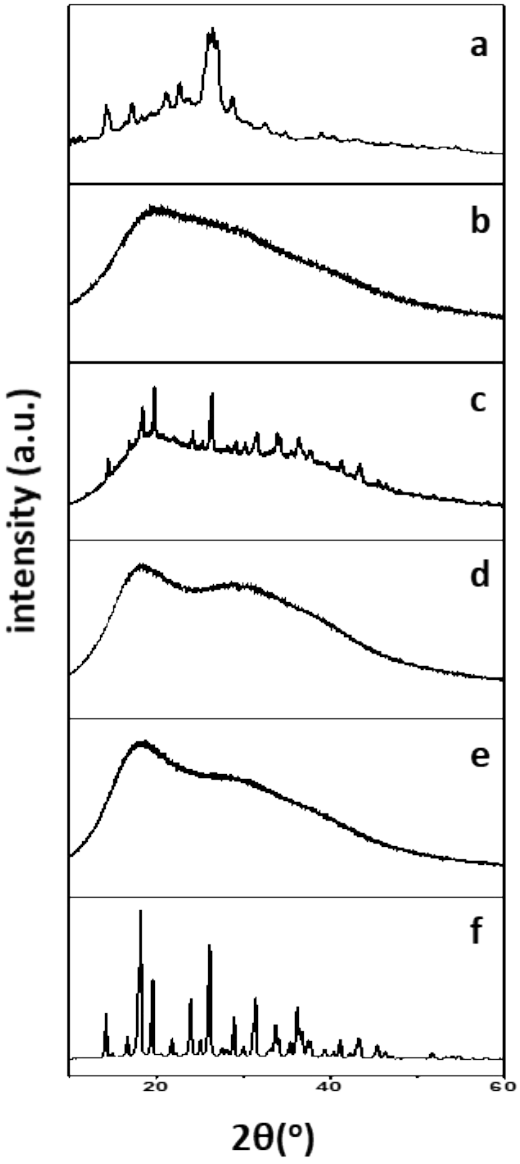

Figure S3. XRD patterns of non-doped **CD** and **N-CD**s; a) **N-CD_1**, b) **N-CD_2**, c) **N-CD_3**, d) **N-CD_4**, e) **N-CD_5**, and f) non-doped **CD**.

IR spectrum of as-synthesized N-CDs

The Fourier transform infrared (FT-IR) spectra were obtained using a Nicolet 6700 (Thermo, United States). In IR spectrum of as-synthesized **N-CD**, there are newly appeared peaks at 1673 cm^{-1} and 1549~1410 cm^{-1} that represent C=C stretching in conjugated alkene and C–N stretching in aromatic amine, respectively.

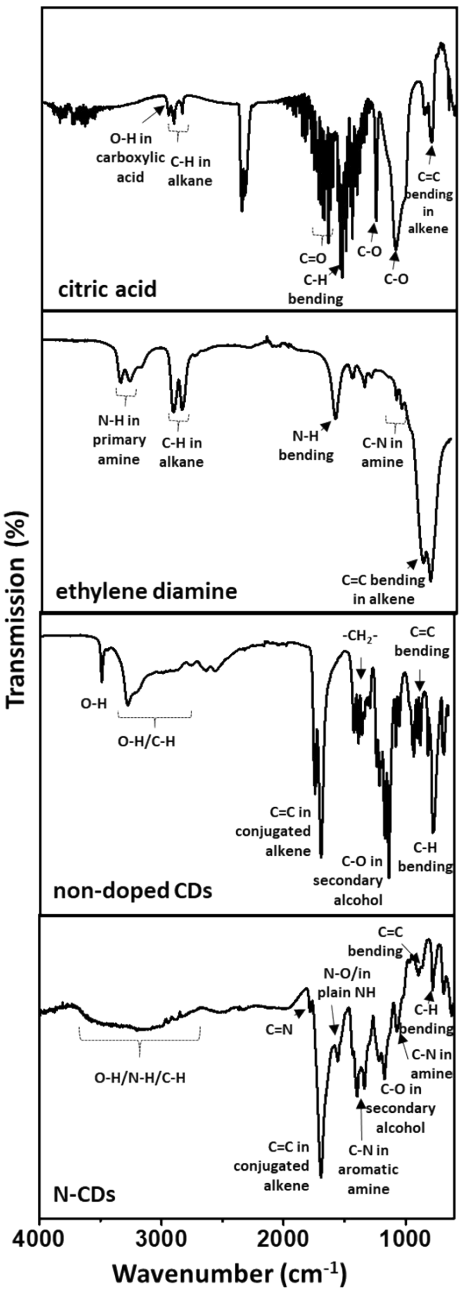

Figure S4. Comparison of IR spectrum between citric acid, ethylenediamine, non-doped **CD**s and as-synthesized **N-CD**s.

Surface charge of N-CDs

The surface charge of **N-CD**s was measured using Zetasizer Nano ZS (Malvern Panalytical, United Kingdom). Overall surface charge of **N-CD**s was negative because of abundant carboxylic groups at the **N-CD** surface.

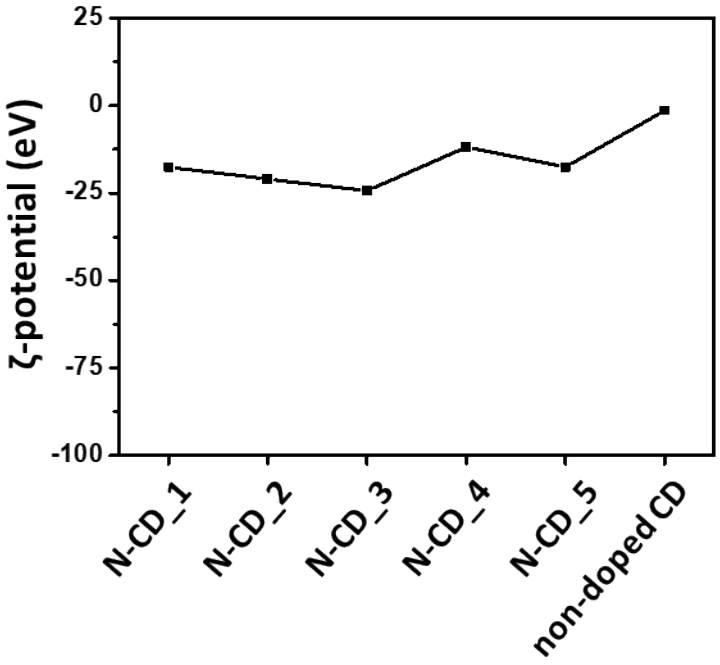

Figure S5. Zeta potential value of **N-CD**s

Comparison of relative atomic composition based on XPS spectra

The chemical composition of **N-CD**s was investigated with X-ray photoelectron spectroscopy (XPS, K-Alpha+, ThermoFisher Scientific, USA). Relative contents of each atom were quantified by measuring the peak area in survey scan spectra are shown in Figure 2a.

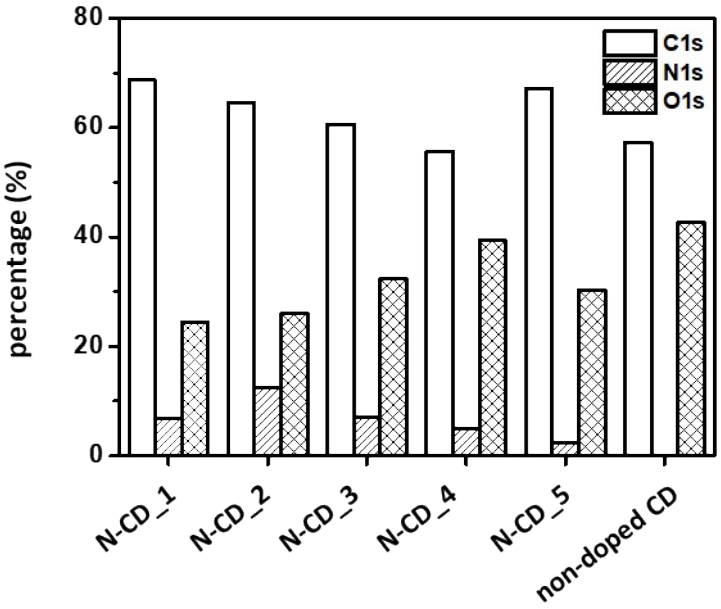

Figure S6. Ratio of each component in **N-CD**s based on XPS peak area.