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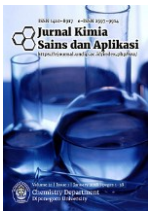

Synthesis and Optical Properties of Carbon Quantum Dots Based on Terung Dayak (*Solanum Ferox)* Fruit Juice as Antioxidant and Metal Ion Sensor

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Abstract

Carbon dots (CDs) are a novel class of carbon-based nanomaterials with diverse applications due to their biocompatibility, optical properties, and chemical stability. This study aims to synthesize CDs from Terung Dayak (*Solanum ferox*) using a microwave-assisted method and evaluate their optical properties, metal ion sensing capability, and antioxidant activity. The CDs were synthesized with variations in microwave power and citric acid concentration, specifically: CD-a using 1 g citric acid at 600 W, CD-b using 2 g citric acid at 600 W, CD-c using 3 g citric acid at 600 W, and CD-d using 2 g citric acid at 800 W, and then characterized using UV-Vis and fluorescence spectroscopy. The results revealed strong UV absorption with maximum peaks at 250 nm for all CDs synthesized and 275 nm for CD-d, depending on synthesis conditions. The CDs exhibited fluorescence intensity influenced by microwave power, with the highest intensity observed for CDs synthesized at 800 W and 2 g of citric acid. The optical bandgap from UV-Vis spectra, determined via Tauc plot analysis, ranged from 4.03 eV to 4.71 eV, indicating quantum confinement effects for all CDs. Furthermore, CD-d demonstrated selective fluorescence quenching for Fe^{3+} ions, which quenched the fluorescence of the CD. Antioxidant activity was confirmed via 2,2-diphenyl-1-picryhydrazyl (DPPH) radical scavenging, with an IC_{50} value of 126 ppm for CD-d. These findings highlight the potential of Terung Dayak-derived CDs as multifunctional materials for sensing and antioxidant applications.

1. Introduction

Carbon quantum dots, also known as carbon dots (CDs), are a novel carbon-based nanomaterial that has attracted significant interest within the scientific community in the last decade. Characterized by the nanoscale size, typically < 10 nm, CDs exhibit excellent biocompatibility, unique thermal and mechanical properties, and strong photodynamic stability [1, 2]. In clinical and medical applications, CDs are primarily applied in cancer theragnostic and bioimaging/biosensing [3, 4, 5, 6]. Furthermore, several CDs can be altered to possess antibacterial and antioxidant properties that can be immobilized into a membrane to prevent food from spoiling [7, 8]. Given their diverse application of CDs, it encourages scientists to further explore the synthesis of CDs, both in terms of methods and precursors used in the synthesis process. The selection of precursor, along with methods, is a key factors that influence the characteristics of CDs [9, 10, 11].

CD synthesis methods are generally divided into two categories: bottom-up and top-down. Top-down methods involve breaking larger carbon materials, such as graphene, graphite, or carbon nanotubes, through physical or chemical processes such as ultrasonication, oxidation, or milling, which break the material into small nano-sized particles [9, 12]. In contrast, bottom-up

methods involve the formation of CD from precursor molecules or atoms through chemical processes, like pyrolysis, thermal decomposition, or solvothermal reactions, which transform the organic precursors into carbon nanostructures of the desired size and properties [9, 13]. Although scientists have focused much emphasis on the hydrothermal synthesis of CD, in recent years, microwave-assisted synthesis of CD is equally worth studying due to its ease of use, simplicity, and compatibility with household microwaves [14, 15, 16]. While the choice of synthesis methods plays a crucial role, selecting appropriate precursors is equally important, as it directly influences the structure of the CD.

Biomass is a potential precursor for CD synthesis and can be derived from various sources, including roots, stems, leaves, and fruits [17, 18, 19]. Several studies have highlighted the advantage of certain biomass sources for use in sensor applications. Watcharamongkol *et al.* [20] successfully synthesized CD from cassava pulp using the hydrothermal method to detect mercury (Hg^{2+}) ions, achieving a detection limit of 12 µM. The presence of Hg^{2+} ions can "turn off" the fluorescence of the CD. In addition, the synthesized CD also demonstrates antioxidant activity, as confirmed through testing using the DPPH scavenging methods. Moreover, in another experiment, Issa *et al.* [21] successfully synthesized carboxymethyl cellulose (CMC)-based CD from oil palm empty fruit bunches, achieving a lower detection limit of 0.01 µM compared to the CD reported by Watcharamongkol *et al.* [20].

Another study by Liang *et al.* [22] reported using the hydrothermal method to synthesize CD from tea waste mixed with ethylenediamine. These synthesized CDs were found to be effective for detecting Fe^{3+} dan CrO_4^{2-} ions. In addition, part fruit or part of the fruit (like peeled fruits) has also been investigated as an eco-friendly precursor for CD synthesis through the hydrothermal-carbonization process. For instance, kiwi peels and watermelon pulp have been reported as effective precursors for producing CD capable of detecting Fe^{3+} ions with a limit of detection of 0.95 µM and 0.27 µM [23, 24]. This highlights that various plant parts, including fruits, can serve as precursors for CD synthesis.

Although these findings demonstrate the versatility of biomass-derived CDs, there remains a clear gap in the literature regarding the use of Terung Dayak (*Solanum ferox*) as a precursor for carbon dot synthesis. Terung Dayak is a plant indigenous to Southeast Asia and South Asia, with a distribution extending to China, Sri Lanka, Myanmar, Thailand, Laos, Malaysia, and Indonesia. This plant belongs to the *Solanaceae* family, like the purple eggplant (*Solanum melongena L.*) [25]. Terung Dayak is rich in phytochemicals such as flavonoids, alkaloids, and phenolic compounds, which could impart unique optical and functional properties to the resulting CDs. To the best of our knowledge, no study has yet reported the synthesis of CDs from Terung Dayak, a fruit native to Central Kalimantan and traditionally used for medicinal and culinary purposes. This research seeks to fill that gap by exploring Terung Dayak as a novel and underutilized biomass source for green nanomaterial synthesis.

This research reports a simple synthesis of highly green synthesis methods using one-pot microwave-assisted synthesis (MAS) to produce fluorescent carbon nanomaterials from Terung Dayak. In addition to addressing this precursor gap, our study also emphasizes the significance of using green synthesis techniques, particularly MAS. Compared to traditional methods like hydrothermal or solvothermal synthesis, MAS offers numerous advantages: it is rapid, energy-efficient, solvent-minimizing, and compatible with simple, low-cost equipment. These attributes make MAS a sustainable and practical approach, aligning with the global movement toward eco-friendly nanotechnology. The one-pot MAS method not only reduces synthesis time but also minimizes the need for hazardous reagents, making it suitable for large-scale production with minimal environmental impact. In this study, our objective is to synthesize CD and identify the optical characteristics of CD from Terung Dayak and its abilities as a metal ion sensing and antioxidant ability through the DPPH scavenging test.

2. Experimental

2.1. Materials and Instrumentations

All chemicals used in this study were of pro-analytical grade, including distilled water, citric acid (Merck), 2,2-diphenyl-1-picrylhydrazyl (DPPH, Merck), ethanol (98%), and Terung Dayak. The carbon dots were synthesized using a household microwave. UV-Vis absorption spectra were recorded using a Marco single-beam spectrophotometer, while fluorescence measurements were carried out with a Shimadzu RF-6000 spectrofluorometer.

2.2. Synthesis of Quantum Dots

The preparation of CDs was based on the methods reported by Ramezani *et al.* [19] and Rajamanikandan *et al.* [26] with some modifications. A total of 10 mL of Terung Dayak juice and varying amounts of citric acid were mixed and transferred into a Teflon microwave container. Citric acid was added to catalyze the carbonization process and promote surface passivation, thereby enhancing the formation of nano-sized fluorescent carbon structures [27]. The variations in citric acid content and microwave power are listed in Table 1. The vessel was then microwaved for 3 minutes at a power range of 600–800 W. After cooling to room temperature, the resulting brown solution was centrifuged at 5000 rpm to separate the precipitate from the supernatant, followed by filtration using a 0.2 µm membrane filter.

Table 1. Variation of citric acid and microwave power

CD code	Citric acid (g)	Microwave power (W)
a	1	
b	2	600
c	3	
d	2	800

2.3. Metal Ion Sensing

A stock solution of metal ions (10 ppm), including Fe^{3+}, Cu^{2+}, Ni^{2+}, Zn^{2+}, and Pb^{2+}, was prepared. For the selectivity test, a 10 ppm solution of CDs was added to each metal ion solution (10 ppm). The fluorescence intensity was measured with an excitation wavelength of 370 nm.

2.4. DPPH Radical Scavenging

The antioxidant activity of the CDs was evaluated using the DPPH radical scavenging assay. A carbon dot solution derived from Terung Dayak was prepared, and a 50 ppm DPPH solution was prepared in ethanol. The DPPH solution was then added to the CD solution, and the mixture was incubated at ambient temperature for 30 minutes in the dark. After incubation, the absorbance was measured at 520 nm using a UV-Vis spectrophotometer. The percentage of DPPH inhibition by the CDs was calculated using Equation 1.

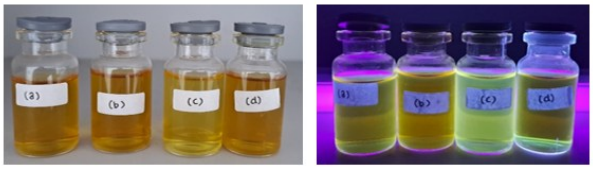
$$\% \, Inhibition = \left[\frac{A_c - A_s}{A_c}\right] \times 100\% \quad (1)$$

Where, A_c is the absorbance of the control (DPPH solution without CDs), and A_s is the absorbance of the DPPH solution after the addition of CDs.

3. Results and Discussion

The synthesis of CDs from Terung Dayak resulted in a color change from light brown to dark brown, indicating the successful formation of carbon nanomaterials [28, 29]. This color transition is attributed to the formation of carbon dots, in which carbon atoms form the nanoparticle core, surrounded by various surface functional groups. After purification, the dark brown solution turned yellowish-brown, as shown in Figure 1(a). Upon exposure to UV light, the synthesized CD solution exhibited luminescence, shifting from a yellowish to an orange fluorescence color. This observation confirms the successful formation of CDs with distinct fluorescent properties under UV irradiation, as illustrated in Figure 1(b).

The luminescence behavior of the synthesized CDs under UV light exposure can be attributed to the quantum confinement effect and the presence of surface functional groups. This is supported by the optical bandgap values obtained from Tauc plot analysis (Figure 3), which range from 4.03 eV to 4.71 eV. The variation in bandgap energy indicates differences in particle size and degree of conjugation among the synthesized CDs. Specifically, CD-d, synthesized at higher microwave power, exhibited the lowest bandgap (4.03 eV) (Figure 3) and the highest photoluminescence intensity (Figure 2), suggesting a more extended π-conjugation system and stronger quantum confinement. The shift in UV-Vis absorption peaks, especially the presence of a second peak at 275–283 nm for CD-a and CD-d, also reflects changes in the electronic structure due to different synthesis conditions. These observations confirm that the optical properties, including fluorescence, are governed by the quantum size effect and surface state modifications unique to each CD variant.



(a) (b)

Figure 1. CDs from Terung Dayak (a) before and (b) after exposure to UV light

In addition, the surface functional groups that contain carbon dots, such as hydroxyl group (-OH), carboxyl (-COO), or amine group ($-NH_2$), introduce localized electronic states of carbon dots. These surface states play a role in the luminescence of CD [30, 31]. Therefore, combining that effect and surface states, CD can emit bright luminescence under UV lights.

The UV absorbance spectra and fluorescence spectra of CD synthesized using different amounts of citric acid and varying microwave power reveal the influence of these parameters on the optical properties of CD. The spectra of UV absorbance and fluorescence are available in Figure 2. The spectra of CD-a exhibit a higher absorbance peak at 250 nm than CD-b and CD-c, but have equal absorbance, respectively, to CD-d, indicating the formation of CD-a with specific surface and size characteristics. The observation is consistent with the fluorescence spectra of the CD, where CD-a has a higher intensity compared to CD-b and CD-c. The increased fluorescence intensity in CD-a suggests that the amount of citric acid plays an important role in the photoluminescence properties of the CD. This phenomenon may also be influenced by the pH conditions during the synthesis process, as a higher amount of citric acid results in more acidic conditions [32].

However, CD-d, which was synthesized using 2-gram citric acid and 800 W microwave power, exhibits a similar fluorescence intensity to CD-a, despite the higher microwave power. This suggests that the increasing power to 800 W likely compensates for any decrease in fluorescence intensity due to a higher citric acid concentration, possibly by promoting more effective carbonization or surface passivation. Furthermore, CD-d shows a new peak exhibited at 275 nm.

All synthesized CDs exhibit a primary absorbance peak at 251 nm in all four synthesis variations. However, in variations CD-a and CD-d, a second maximum wavelength was obtained at 276 nm for CD-d and 283 nm for CD-a. The absorption in the wavelength region of 251 nm is expected to be the $\pi \rightarrow \pi^*$ electron transition of the carbon double bond (C=C). The broadened absorption at λ = 276-283 nm indicates the $n \rightarrow \pi^*$ electron transition, which is usually present in carbonyl groups (C=O) [33]. The existence of a significant absorption at λ = 276 nm indicates that CD-d experienced surface modification because it contains carbonyl groups (C = O) compared to CD-b and CD-c.

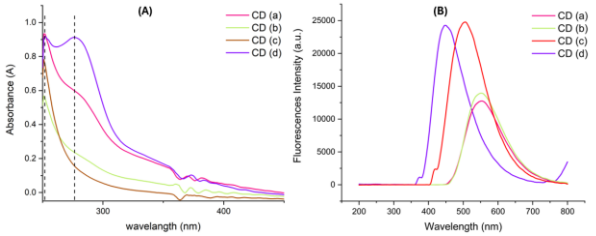


Figure 2. (a) UV-Vis absorbance spectrum and (b) fluorescence emission profile of CDs

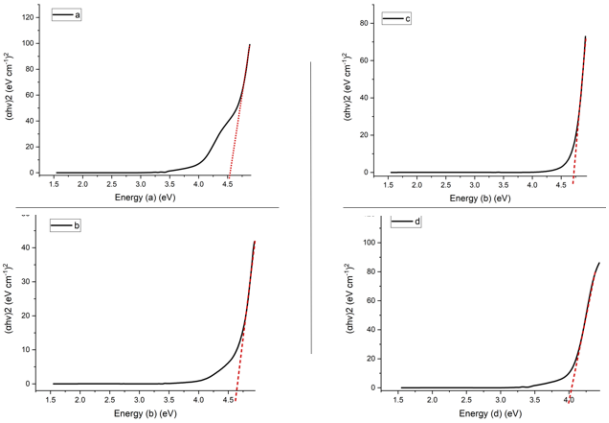


Figure 3. Tauc plot of optical band gap on the CD from Terung Dayak with the variation of citric acid

The Tauc plot analysis is a widely used method to determine the optical band gap energy (e.g., CD) of semiconductor materials. The optical band gap energy is an important parameter that governs the optical and electronic properties of a material, such as its light absorption and fluorescence behavior [34, 35]. The Tauc plot is constructed using the relationship between the absorption (α) and the photon energy ($h\nu$), defined in Equation 2.

$$(\alpha h\nu)^n = A(h\nu - E_g) \quad (2)$$

Where, α is the absorption coefficient, $h\nu$ is the photon energy, n depends on the nature of the electronic transition (n = 2 or n = ½), A is a proportion constant, and E_g is the bandgap energy. The E_g value is determined by extrapolating the linear region of the Tauc plot to the photon energy axis.

The optical bandgap energies of the synthesized CDs were estimated using Tauc plot analysis. CD-a, synthesized with 1 g of citric acid at 600 W, exhibited a bandgap energy of 4.53 eV. In comparison, CD-b and CD- c, prepared with 2 g and 3 g citric acid, respectively, showed higher bandgap energies of 4.64 eV and 4.71 eV. Meanwhile, CD-d (800 W) exhibited the lowest bandgap of 4.03 eV. This trend can be explained by the Brus equation (3) [36].

$$\Delta E = E_{bulk} + \frac{h^2}{8r^2}\left(\frac{1}{m_e^*} + \frac{1}{m_h^*}\right) - \frac{1.8e^2}{4\pi\epsilon_o\epsilon_r R^2} \quad (3)$$

The energy gap of a quantum dot is inversely related to its size due to quantum confinement effects. As particle size decreases, the spatial confinement of charge carriers (electrons and holes) increases, leading to discrete energy levels and a larger bandgap. Accordingly, the observed trend suggests that CD-c, which has the highest bandgap energy (4.71 eV), likely possesses the smallest particle size, followed by CD-b and CD-a. In contrast, CD-d, which exhibited the lowest bandgap energy (4.03 eV), is likely composed of larger carbon cores or more extended conjugation structures, possibly resulting from enhanced carbonization under higher microwave power.

These findings confirm that variations in synthesis conditions affect not only surface functionalities but also the size and electronic structure of the resulting carbon dots. Moreover, the results indicate that microwave irradiation power influences the structural formation of CDs. Higher power, under the same reaction time, accelerates the nucleation of CDs and promotes the formation of sp^2-hybridized carbon, thereby reducing the bandgap energy [37].

After examining the optical properties and energy gap of synthesized CD, the metal sensing ability of the synthesized CD was investigated for various metal ions, including Fe^{3+}, Cu^{2+}, Ni^{2+}, Zn^{2+}, and Pb^{2+}. The sensing ability of the synthesized CDs toward Fe^{3+}, Cu^{2+}, Ni^{2+}, Pb^{2+}, and Zn^{2+} ions was evaluated through UV-Vis and fluorescence spectroscopy. As shown in Figure 4(a), the UV-Vis analysis revealed a consistent reduction in absorbance at 278 nm across all tested metal ions, indicating their interaction with the CDs. This behavior aligns with previous studies, where interactions between metal ions and surface functional groups of CDs, such as hydroxyl and carboxyl groups, resulted in alterations in optical properties [28, 38].

Interestingly, fluorescence analysis demonstrated a more selective response. While Cu^{2+}, Ni^{2+}, Pb^{2+}, and Zn^{2+} ions enhanced the fluorescence intensity of the CDs, Fe^{3+} ions uniquely quenched the fluorescence. This quenching suggests a distinct interaction mechanism, likely involving the formation of coordination complexes or charge transfer between Fe^{3+} and the CDs, as reported in studies utilizing similar nanomaterials for Fe ion detection [28, 39]. Such specific quenching behavior highlights the potential of the CDs as selective fluorescence probes for Fe^{3+} ions.

The pronounced fluorescence quenching observed with Fe^{3+} ions is consistent with findings from Chen *et al.* [28], who demonstrated that surface defects and specific functional groups on CDs are critical for their interaction with metal ions. Furthermore, the fluorescence recovery tests for Fe^{3+} by Chen *et al.* [28] indicate that the interaction between CDs and Fe ions involves non-radiative electron transfer, providing further evidence for the observed selectivity. This mechanism underscores the practical application of these CDs as sensitive and selective probes for Fe ion detection in complex matrices.

The antioxidant activity of CD was evaluated using the DPPH scavenging method. CD solutions at various concentrations (10–50 ppm) were analyzed using a UV- Vis spectrophotometer. Measurement was conducted by observing the decrease in absorbance at 517 nm, corresponding to the maximum wavelength of DPPH. The results showed a concentration-dependent effect, where higher CD concentrations led to a greater reduction in DPPH absorbance.

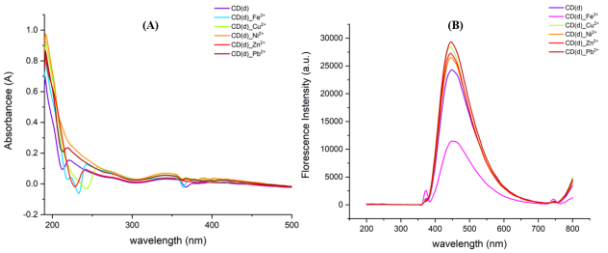


Figure 4. (a) UV-Vis absorbance spectrum of CDs, (b) Photoluminescence (PL) spectra comparison between original CDs and CDs after the addition of various metal ions, highlighting fluorescence quenching or enhancement effects

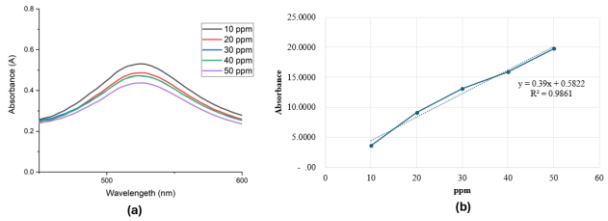


Figure 5. (a) UV-Vis absorbance at 520 nm showing DPPH scavenging by CDs, (b) IC_{50} determination from linear regression of scavenging activity

At a concentration of 50 ppm, the CD demonstrated the highest DPPH degradation, indicated by the lowest absorbance value (Figure 5). This result indicates that the synthesized CD exhibits antioxidant properties, likely due to the presence of functional groups such as double bonds, carbonyl groups, or hydroxyl groups, which are known to act as active sites for antioxidant activity. A plot of CD concentration vs percent inhibition yielded a linear equation y = 0.39x + 0.5822, with a correlation coefficient (R^2) of 0.9861. Based on that equation, the IC_{50} value of the CD synthesized from Terung Dayak was determined to be 126 ppm.

4. Conclusion

This study demonstrated that variation in microwave power and citric acid concentration significantly influenced the optical and functional properties of carbon dots synthesized from Terung Dayak. Among the samples, CD-d—produced at 800 W with 2 g of citric acid—exhibited the most notable characteristics, including the highest fluorescence intensity, the lowest optical bandgap (4.03 eV), and strong selectivity for Fe^{3+} ions through a "turn-off" fluorescence mechanism. In addition, CD-d showed promising antioxidant activity, with an IC_{50} value of 126 ppm. These findings highlight the potential of Terung Dayak-derived CDs as multifunctional nanomaterials for metal ion sensing and antioxidant applications, with implications for future green nanotechnology and biosensing research.

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References

[1] Pranoti Kamble, Dhanaji Malavekar, Arpita Pandey Tiwari, Natural Biowaste Derived Fluorescent Carbon Quantum Dots: Synthesis, Characterization and Biocompatibility Study, *Journal of Fluorescence*, 34, 1, (2024), 191-201 https://doi.org/10.1007/s10895-023-03244-w

[2] Shi Ying Lim, Wei Shen, Zhiqiang Gao, Carbon quantum dots and their applications, *Chemical Society Reviews*, 44, 1, (2015), 362-381 https://doi.org/10.1039/C4CS00269E

[3] Łukasz Janus, Julia Radwan-Pragłowska, Marek Piątkowski, Dariusz Bogdał, Facile Synthesis of Surface-Modified Carbon Quantum Dots (CQDs) for Biosensing and Bioimaging, *Materials*, 13, 15, (2020), 3313 https://doi.org/10.3390/ma13153313

[4] Boyang Wang, Huijuan Cai, Geoffrey I. N. Waterhouse, Xiaoli Qu, Bai Yang, Siyu Lu, Carbon Dots in Bioimaging, Biosensing and Therapeutics: A Comprehensive Review, *Small Science*, 2, 6, (2022), 2200012 https://doi.org/10.1002/smsc.202200012

[5] Hongxia Li, Xu Yan, Deshuai Kong, Rui Jin, Chunyan Sun, Dan Du, Yuehe Lin, Geyu Lu, Recent advances in carbon dots for bioimaging applications, *Nanoscale Horizons*, 5, 2, (2020), 218-234 https://doi.org/10.1039/C9NH00476A

[6] Qianghua Ye, Fanyong Yan, Dechao Shi, Tancheng Zheng, Yinyin Wang, Xuguang Zhou, Li Chen, N, B-doped carbon dots as a sensitive fluorescence probe for Hg^{2+} ions and 2,4,6-trinitrophenol detection for bioimaging, *Journal of Photochemistry and Photobiology B: Biology*, 162, (2016), 1-13 https://doi.org/10.1016/j.jphotobiol.2016.06.021

[7] Parya Ezati, Ruchir Priyadarshi, Jong-Whan Rhim, Prospects of sustainable and renewable source-based carbon quantum dots for food packaging applications, *Sustainable Materials and Technologies*, 33, (2022), e00494 https://doi.org/10.1016/j.susmat.2022.e00494

[8] Deepika, Lokesh Kumar, Kirtiraj K. Gaikwad, Carbon dots for food packaging applications, *Sustainable Food Technology*, 1, 2, (2023), 185-199 https://doi.org/10.1039/D2FB00020B

[9] Timothy J. Pillar-Little, Namal Wanninayake, Leona Nease, David K. Heidary, Edith C. Glazer, Doo Young Kim, Superior photodynamic effect of carbon quantum dots through both type I and type II pathways: Detailed comparison study of top-down-synthesized and bottom-up-synthesized carbon quantum dots, *Carbon*, 140, (2018), 616-623 https://doi.org/10.1016/j.carbon.2018.09.004

[10] Hong Hee Kim, Yeon Ju Lee, Chanho Park, Seunggun Yu, Sung Ok Won, Won-Seon Seo, Cheolmin Park, Won Kook Choi, Bottom-Up Synthesis of Carbon Quantum Dots With High Performance Photo- and Electroluminescence, *Particle & Particle Systems Characterization*, 35, 7, (2018), 1800080 https://doi.org/10.1002/ppsc.201800080

[11] Siwei Yang, Yongqiang Li, Liangfeng Chen, Hang Wang, Liuyang Shang, Peng He, Hui Dong, Gang Wang, Guqiao Ding, Fabrication of Carbon-Based Quantum Dots via a "Bottom-Up" Approach: Topology, Chirality, and Free Radical Processes in "Building Blocks", *Small*, 19, 31, (2023), 2205957 https://doi.org/10.1002/smll.202205957

[12] Yen-Linh Thi Ngo, Jayasmita Jana, Jin Suk Chung, Seung Hyun Hur, Electrochemical Biosensors based on Nanocomposites of Carbon-based Dots, *Korean Chemical Engineering Research*, 58, 4, (2020), 499-513 https://doi.org/10.9713/kcer.2020.58.4.499

[13] Diana M. A. Crista, Joaquim C. G. Esteves da Silva, Luís Pinto da Silva, Evaluation of Different Bottom-up Routes for the Fabrication of Carbon Dots, *Nanomaterials*, 10, 7, (2020), 1316 https://doi.org/10.3390/nano10071316

[14] Tayline V. de Medeiros, John Manioudakis, Farah Noun, Jun-Ray Macairan, Florence Victoria, Rafik Naccache, Microwave-assisted synthesis of carbon dots and their applications, *Journal of Materials Chemistry C*, 7, 24, (2019), 7175-7195 https://doi.org/10.1039/C9TC01640F

[15] Tutuk Budiati, Ami Soewandi, Lisa Soegianto, Microwave-assisted Synthesis of Dibenzalacetone Derivatives and Study of their Potential Antioxidant Activities, *Journal of Chemical and Pharmaceutical Research*, 11, 9, (2019), 11-16

[16] Chunxi Zhao, Xiao Li, Chunsheng Cheng, Yaling Yang, Green and microwave-assisted synthesis of carbon dots and application for visual detection of cobalt(II) ions and pH sensing, *Microchemical Journal*, 147, (2019), 183-190 https://doi.org/10.1016/j.microc.2019.03.029

[17] Swarup Roy, Parya Ezati, Jong-Whan Rhim, Rahim Molaei, Preparation of turmeric-derived sulfur-functionalized carbon dots: antibacterial and antioxidant activity, *Journal of Materials Science*, 57, 4, (2022), 2941-2952 https://doi.org/10.1007/s10853-021-06804-2

[18] Xinzhu Huo, Yuxuan He, Shiqi Ma, Yingying Jia, Jiaming Yu, Yu Li, Qian Cheng, Green Synthesis of Carbon Dots from Grapefruit and Its Fluorescence Enhancement, *Journal of Nanomaterials*, 2020, 1, (2020), 8601307 https://doi.org/10.1155/2020/8601307

[19] Zahra Ramezani, Maryam Qorbanpour, Nadereh Rahbar, Green synthesis of carbon quantum dots using quince fruit (*Cydonia oblonga*) powder as carbon precursor: Application in cell imaging and As^{3+} determination, *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 549, (2018), 58-66 https://doi.org/10.1016/j.colsurfa.2018.04.006

[20] Teera Watcharamongkol, Pacharaphon Khaopueak, Chuleekorn Seesuea, Kanokorn Wechakorn, Green hydrothermal synthesis of multifunctional carbon dots from cassava pulps for metal sensing, antioxidant, and mercury detoxification in plants, *Carbon Resources Conversion*, 7, 2, (2024), 100206 https://doi.org/10.1016/j.crcon.2023.100206

[21] Mohammed Abdullah Issa, Hamid Zentou, Zaid H. Jabbar, Zurina Z. Abidin, Haninah Harun, Noor Amirah Abdul Halim, Mohammed M. Alkhabet, Musa Y. Pudza, Ecofriendly adsorption and sensitive detection of Hg (II) by biomass-derived nitrogen-doped carbon dots: process modelling using central composite design, *Environmental Science and Pollution Research*, 29, 57, (2022), 86859-86872 https://doi.org/10.1007/s11356-022-21844-0

[22] Jia Yu Liang, Lei Han, Shi Gang Liu, Yan Jun Ju, Nian Bing Li, Hong Qun Luo, Carbon dots-based fluorescent turn off/on sensor for highly selective and sensitive detection of Hg^{2+} and biothiols, *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 222, (2019), 117260 https://doi.org/10.1016/j.saa.2019.117260

[23] Meice Lu, Yixing Duan, Yiheng Song, Jisuan Tan, Li Zhou, Green preparation of versatile nitrogen-doped carbon quantum dots from watermelon juice for cell imaging, detection of Fe^{3+} ions and cysteine, and optical thermometry, *Journal of Molecular Liquids*, 269, (2018), 766-774 https://doi.org/10.1016/j.molliq.2018.08.101

[24] Raji Atchudan, Thomas Nesakumar Jebakumar Immanuel Edison, Suguna Perumal, Rajangam Vinodh, Ashok K. Sundramoorthy, Rajendran Suresh Babu, Yong Rok Lee, Leftover Kiwi Fruit Peel-Derived Carbon Dots as a Highly Selective Fluorescent Sensor for Detection of Ferric Ion, *Chemosensors*, 9, 7, (2021), 166 https://doi.org/10.3390/chemosensors9070166

[25] Lilis Rosmainar, Erwin Prasetya Toepak, Wahyu Nugroho, Skrining Fitokimia dan Uji Antioksidan Menggunakan Metode DPPH Pada Ekstrak Metanol Buah Terung Asam Besar (*Solanum ferox* Linn), *Jurnal Crystal : Publikasi Penelitian Kimia dan Terapannya*, 5, 1, (2023), 30 - 39 https://doi.org/10.36526/jc.v5i1.2590

[26] Sundaraj Rajamanikandan, Muniyandi Biruntha, Gopal Ramalingam, Blue Emissive Carbon Quantum Dots (CQDs) from Bio-waste Peels and Its Antioxidant Activity, *Journal of Cluster Science*, 33, 3, (2022), 1045-1053 https://doi.org/10.1007/s10876-021-02029-0

[27] Xiaoxiao Li, Xutong Liu, Yuhang Su, Tianyu Jiang, Dongna Li, Xiaojun Ma, Green synthesis of carbon quantum dots from wasted enzymatic hydrolysis lignin catalyzed by organic acids for UV shielding and antioxidant fluorescent flexible film, *Industrial Crops and Products*, 188, (2022), 115568 https://doi.org/10.1016/j.indcrop.2022.115568

[28] Kui Chen, Weixia Qing, Weiping Hu, Minghua Lu, Yong Wang, Xiuhua Liu, On-off-on fluorescent carbon dots from waste tea: Their properties, antioxidant and selective detection of CrO_4^{2-}, Fe^{3+}, ascorbic acid and L-cysteine in real samples, *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 213, (2019), 228-234 https://doi.org/10.1016/j.saa.2019.01.066

[29] Nichaphat Thongsai, Panichakorn Jaiyong, Sumana Kladsomboon, Insik In, Peerasak Paoprasert, Utilization of carbon dots from jackfruit for real-time sensing of acetone vapor and understanding the electronic and interfacial interactions using density functional theory, *Applied Surface Science*, 487, (2019), 1233-1244 https://doi.org/10.1016/j.apsusc.2019.04.269

[30] Wenjuan Liang, Zhixi Li, Hao Li, Zhipeng Liu, Xin Wang, Kun Yang, The Influence of Functional Group on Photoluminescence Properties of Carbon Dots, *ECS Journal of Solid State Science and Technology*, 8, 12, (2019), R176 https://doi.org/10.1149/2.0131912jss

[31] Jian Ren, Fabian Weber, Florian Weigert, Yajie Wang, Sneha Choudhury, Jie Xiao, Iver Lauermann, Ute Resch-Genger, Annika Bande, Tristan Petit, Influence of surface chemistry on optical, chemical and electronic properties of blue luminescent carbon

dots, *Nanoscale*, 11, 4, (2019), 2056-2064 https://doi.org/10.1039/C8NR08595A

[32] Chuanxi Wang, Zhenzhu Xu, Chi Zhang, Polyethyleneimine-Functionalized Fluorescent Carbon Dots: Water Stability, pH Sensing, and Cellular Imaging, *ChemNanoMat*, 1, 2, (2015), 122-127 https://doi.org/10.1002/cnma.201500009

[33] Mohammad Amjadi, Tooba Hallaj, Hamideh Asadollahi, Zhenlun Song, Marta de Frutos, Niko Hildebrandt, Facile synthesis of carbon quantum dot/silver nanocomposite and its application for colorimetric detection of methimazole, *Sensors and Actuators B: Chemical*, 244, (2017), 425-432 https://doi.org/10.1016/j.snb.2017.01.003

[34] Albert Zicko Johannes, Redi Kristian Pingak, Minsyahril Bukit, Tauc Plot Software: Calculating energy gap values of organic materials based on Ultraviolet-Visible absorbance spectrum, *IOP Conference Series: Materials Science and Engineering*, 823, 1, (2020), 012030 https://doi.org/10.1088/1757-899X/823/1/012030

[35] Jumardin Jumardin, Akhiruddin Maddu, Koekoeh Santoso, Isnaeni Isnaeni, Synthesis of carbon dots (CDS) and determination of optical gap energy with Tauc plot method, *Jambura Physics Journal*, 3, 2, (2021), 73-86 https://doi.org/10.34312/jpj.v3i2.11235

[36] L. E. Brus, Electron - electron and electron - hole interactions in small semiconductor crystallites: The size dependence of the lowest excited electronic state, *The Journal of Chemical Physics*, 80, 9, (1984), 4403-4409 https://doi.org/10.1063/1.447218

[37] H. Sutanto, I. Alkian, N. Romanda, I. W. L. Lewa, I. Marhaendrajaya, P. Triadyaksa, High green-emission carbon dots and its optical properties: Microwave power effect, *AIP Advances*, 10, 5, (2020), 055008 https://doi.org/10.1063/5.0004595

[38] Mikail Aslan, Hasan and Eskalen, A study of carbon nanodots (carbon quantum dots) synthesized from tangerine juice using one-step hydrothermal method, *Fullerenes, Nanotubes and Carbon Nanostructures*, 29, 12, (2021), 1026-1033 https://doi.org/10.1080/1536383X.2021.1926452

[39] Muhammad Nazar, Muhammad Hasan, Basuki Wirjosentono, Basri A. Gani, Cut Elvira Nada, Microwave Synthesis of Carbon Quantum Dots from Arabica Coffee Ground for Fluorescence Detection of Fe^{3+}, Pb^{2+}, and Cr^{3+}, *ACS Omega*, 9, 18, (2024), 20571-20581 https://doi.org/10.1021/acsomega.4c02254