



# Utilization Carbon quantum dots derived from organic waste materials: Synthesis, characterization, and application for the detection of dopamine and serotonin by using UV- VIS spectroscopy

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by

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# Utilization of Carbon Quantum Dots Derived from Organic Waste Materials for UV Based Selective Detection of Dopamine

## Abstract

Nanotechnology has emerged as a revolutionary field, offering innovative solutions to global challenges by manipulating materials at the nanoscale. Among these nanoparticles, carbon quantum dots (CQDs) have garnered considerable attention due to their unique optical, electronic and biocompatible properties, making them ideal for diverse applications in biosensing, imaging and catalysis. The traditional CQD synthesis often relies on costly and non eco friendly methods whereas, the use of organic waste materials as precursors provides a sustainable and cost effective alternative. In Organic waste there is lots of carbon based components, which makes it an excellent resource for green synthesis methods. This study presents the synthesis of CQDs carried out from watermelon peels (WP) and orange peels (OP) as carbon sources employing microwave assisted (MW) and hydrothermal methods (HT). The synthesized CQDs were purified using high-speed centrifugation (15,000 rpm) and dialysis membranes to ensure uniform size and optimal performance for advanced sensing and photocatalytic applications. The CQDs showed an average particle size of 1–4 nm, as determined by Dynamic Light Scattering (DLS) and a zeta potential of approximately -25 mV, ensuring excellent colloidal stability. Structural and optical characterization that can be pointing that are Fourier transform infrared spectroscopy (FTIR) and photoluminescence (PL) analysis revealed the presence of functional groups such as hydroxyl (-OH), carboxyl (-COOH) and amine (-NH<sub>2</sub>), along with strong fluorescence. Properties it shows the maximum emission at 450 nm when excited at 360 nm. UV Vis spectroscopy confirmed absorption peaks at 270 nm and 280 nm, indicative of the  $\pi$ - $\pi^*$  transitions of aromatic structures. The CQDs demonstrated exceptional sensitivity in detecting neurotransmitters (dopamine and serotonin). The limit of detection (LOD) for dopamine ranged is 1–5 nM and serotonin detection showed similar precision, both

utilizing fluorescence quenching via electron transfer mechanisms. Selectivity tests with bovine serum albumin (BSA) exhibited minimal interaction, validating the CQDs specificity for neurotransmitters. In addition to biosensing, the photocatalytic capabilities of CQDs were evaluated through dye degradation experiments. The CQDs achieved 85% degradation of methylene blue (MB) and 90% degradation of methyl orange (MO) under UV light, demonstrating their effectiveness in environmental remediation. This research emphasizes the dual functionality of CQDs as sensitive and selective biosensors for neurotransmitter detection and as efficient photocatalysts for dye degradation. The sustainable synthesis approach using organic waste materials enhances the ecological and economic viability of CQD based applications, paving the way for advancements in nanotechnology, biomedical research and environmental science. **This project is supported by TÜBİTAK (The Scientific and Technological Research Council of Turkey) under project number 224Z052.** We gratefully acknowledge TÜBİTAK for their financial support.

**Keywords:** Eco Friendly Synthesis, Carbon Quantum Dots (CQDs), Dopamine, serotonin, UV Vis spectroscopy

# Organik Atık malzemelerde Elde Edilen Karbon Kuantum Noktalarının Dopaminin UV Tabanlı Seçici Tespitinde kullanılması

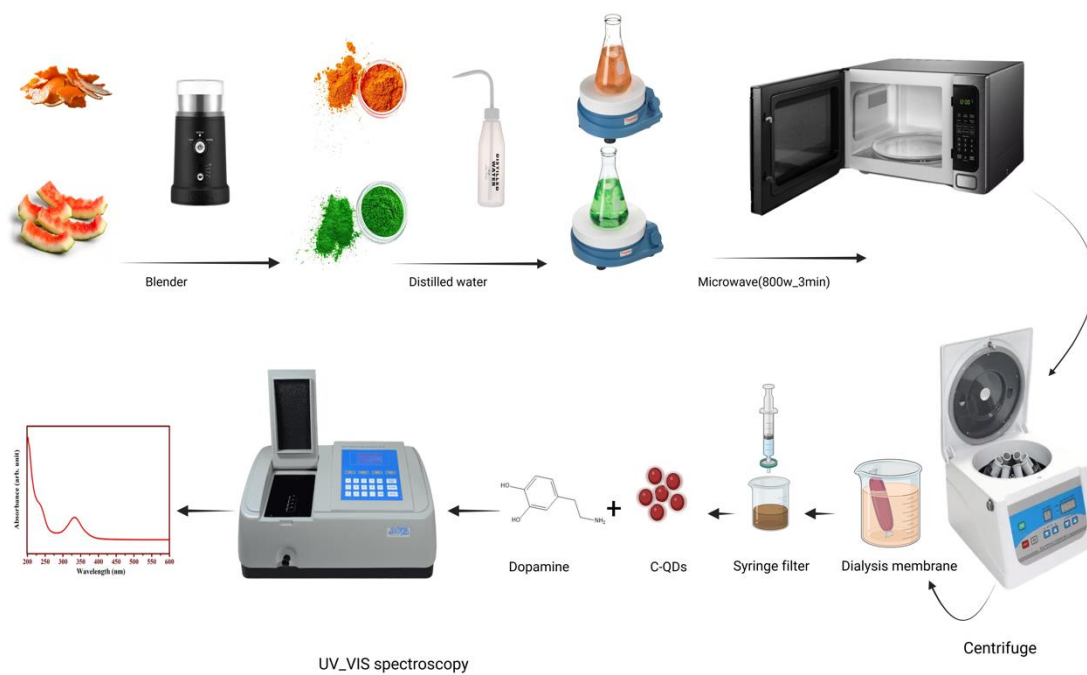
## ÖZ

Nanoteknoloji, malzemeleri nanoskalada manipüle ederek küresel zorluklara yenilikçi çözümler sunan devrim niteliğinde bir alan olarak ortaya çıkmıştır. Bu nanopartiküller arasında, karbon kuantum noktaları (CQD'ler) benzersiz optik, elektronik ve biyouyumlu özellikleri nedeniyle önemli bir dikkat çekmiştir, bu da onları biyosensör, görüntüleme ve kataliz gibi çeşitli uygulamalar için ideal hale getirmektedir. Geleneksel CQD sentezi genellikle maliyetli ve çevre dostu olmayan yöntemlere dayanırken, organik atık malzemelerin öncü olarak kullanılması sürdürülebilir ve maliyet etkin bir alternatif sunar. Organik atık, karbon bazlı bileşenler açısından zengin olup, yeşil sentez yöntemleri için mükemmel bir kaynak oluşturmaktadır. Bu çalışma, karpuz kabukları (WP) ve portakal kabukları (OP) kullanılarak karbon kaynakları olarak CQD'lerin mikrodalga destekli (MW) ve hidrotermal yöntemler (HT) ile sentezlenmesini sunmaktadır. Sentetik CQD'ler, ileri düzey algılama ve fotokatalitik uygulamalar için uniform boyut ve optimal performans sağlamak amacıyla yüksek hızlı santrifüj (15.000 rpm) ve diyaliz zarları kullanılarak saflaştırıldı. CQD'ler, Dinamik Işık Saçılması (DLS) ile belirlenen ortalama 1–4 nm partikül boyutuna ve yaklaşık -25 mV zeta potansiyeline sahip olup, mükemmel koloidal stabilite sağladı. Yapısal ve optik karakterizasyonlar, Fourier Dönüşümlü Kızılötesi Spektroskopisi (FTIR) ve Fotoluminesans (PL) analizi dahil olmak üzere, hidroksil (-OH), karboksil (-COOH) ve amin (-NH<sub>2</sub>) gibi fonksiyonel grupların varlığını ortaya koymuş, ayrıca 360 nm'de uyarıldığında maksimum emisyon 450 nm'de güçlü floresan özellikler göstermiştir. UV-Vis spektroskopisi, aromatik yapıların  $\pi$ - $\pi^*$  geçişlerini gösteren 270 nm ve 280 nm'de absorpsiyon zirvelerini doğruladı. CQD'ler, nörotransmitterleri (dopamin ve serotonin) tespit etmede olağanüstü hassasiyet gösterdi. Dopamin için tespit sınırı (LOD) 1–5 nM aralığında olup, serotonin tespiti de benzer hassasiyet göstermiştir;

her ikisi de elektron transfer mekanizmaları aracılığıyla floresans sönümlenmesi kullanmaktadır. Sığır serum albümini (BSA) ile yapılan seçicilik testleri, CQD'lerin nörotransmitterler için özgülüğünü doğrulayan minimal etkileşimler sergiledi. Biyosensörlüğün yanı sıra, CQD'lerin fotokatalitik yetenekleri boya bozunma deneyleri ile değerlendirildi. CQD'ler, UV ışık altında metilen mavisi (MB) için %85 ve metil turuncusu (MO) için %90 bozulma sağladı ve bu da çevresel iyileştirme konusundaki etkinliklerini gösterdi. Bu araştırma, CQD'lerin nörotransmitter tespiti için hassas ve seçici biyosensörler ve boya parçalanması için verimli fotokatalizörler olarak çift işlevselliğini vurgulamaktadır. Organik atık malzemelerin kullanıldığı sürdürülebilir sentez yaklaşımı, CQD tabanlı uygulamaların ekolojik ve ekonomik uygulanabilirliğini artırarak nanoteknoloji, biyomedikal araştırmalar ve çevre bilimlerinde ilerlemelerin yolunu açmaktadır. **Bu proje, TÜBİTAK (Türkiye Bilimsel ve Teknolojik Araştırma Kurumu) tarafından 224Z052 proje numarasıyla desteklenmiştir.** TÜBİTAK'a maddi destekleri için minnettarız.

**Anahtar Kelimeler:** Ekolojik Dost Sentez, Karbon Kuantum Noktaları (CQDs), Dopamin, serotonin, UV-Vis spektroskopisi

# Graphical abstract



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# List of Abbreviations

**CQDs:** Carbon quantum dots

**WP:** Watermelon peels

**OP:** Orange peels

**MW:** Microwave assisted

**HT:** Hydrothermal

**FTIR:** Fourier Transmission Infrared Spectroscopy

**DLS:** Dynamic Light Scattering

**SEM:** Scanning Electron Microscopy

**PL:** Photoluminescence

**LOD:** Limit of detection

**BSA:** Bovine serum albumin

**MO:** Methyl orange

**MB:** Methylene blue

# List of Symbols

°	degrees
<i>n</i>	nano
<i>nm</i>	nanometer



# Chapter 1

## 1. Introduction

In recent years, the development of science and technology has brought significant progress in various fields including medicine, energy and environmental improvement. Amidst these advances, nanotechnology has emerged as a new innovation that offers innovative solutions to critical global problems. Nanotechnology focuses on nanoscale materials (1-100 nm) where their physical, chemical, and optical properties exhibit unique behaviors that differ from bulk materials. The characteristics of high surface area, quantum confinement, and tunable fluorescence have created new avenues for applications in biomedicine, electronics, catalysis, and environmental science.

In the field of nanotechnology, nanomaterials have emerged as tools that can do anything. Nanomaterials that can be pointing are carbon nanotubes, graphene oxide, metal oxide nanoparticles, and quantum dots, exhibit remarkable properties that can be used for various applications. Because of their low toxicity, biocompatibility, water solubility, and fluorescent qualities, CQDs have become a novel type of nanomaterials. The properties of CQDs make them suitable for use in biosensing, drug delivery, and photocatalysis [1].

Synthesis of nanomaterials including CQDs was often possible with hazardous chemicals as well as very high energy and cost. This has led to increasing concerns about the environmental consequences of traditional synthesis methods. Researchers have adopted green synthesis methods that utilize renewable and abundant resources including organic waste materials to address these challenges.

Organic wastes such as agricultural residues, fruit peels and biomass are sources that can be used to produce sustainable nanomaterials. Organic wastes contain high

levels of carbon-based components such as cellulose, lignin and pectin, which can act as natural carbon precursors for CQD synthesis [2].

This study utilizes organic waste materials, specifically WP and OP, as sustainable precursors for CQD synthesis via MW and HT methods. The CQDs, characterized by a particle size of 1–4 nm and a zeta potential of -25 mV, demonstrated excellent colloidal stability, strong fluorescence and selective biosensing capabilities for neurotransmitters like dopamine and serotonin. Additionally, they achieved significant photocatalytic efficiency, degrading up to 90 of dyes such as methylene blue and methyl orange under UV light. By mixing ecofriendly synthesis with two of the applications including in biosensing and environmental remediation, this study highlights to the potential of CQDs to advance facing nanotechnology.

## 1. 1 Carbon Quantum Dots (CQDs)

### 1. 1. 1 Definition and Structure of CQDs

A type of carbon based nanomaterials that known as an CQDs has the ability to display chemical, optical, and electrical characteristics. CQDs are mainly made from carbon-rich materials and generally exhibit sizes between 2 and 10 nm [3]. The materials in question, due to their remarkable biocompatibility, low toxicity, and eco-friendly characteristics, are reasons that have made these materials the ones that are in discussion today, especially when contrasted with conventional semiconductor quantum dots (like CdSe, CdTe) that often contain heavy metals and pose environmental hazards [4]. The optical and fluorescence properties of CQDs, as illustrated in Figure 1.1, make them particularly attractive for diverse applications.

The discovery of CQDs occurred in the early 2000s, when researchers aimed to find safer and more environmentally friendly alternatives to metal-based quantum dots [5]. CQDs consist of a  $sp^2$  hybridized carbon core surrounded by functionalized surface groups, for example carboxyl ( $-COOH$ ), hydroxyl ( $-OH$ ) and amino ( $NH_2$ ) moieties. This core shell structure is key to their versatile optical properties, as the core decides the quantum detention effect and the surface groups influence fluorescence and solubility [6].

The basic properties of CQDs are summarized as follows: Because of their small spatial dimensions, these nanostructures, which range in size from 2 to 10 nm, are categorized as zero dimensional. CQDs consist of a carbon core, typically amorphous or semi-crystalline, that is coated with a variety of functional groups that increase their versatility. This combination increases their surface area and tunable fluorescence, making them suitable for various applications. Their high water solubility and easy dissolution in water and other solvents increase their applicability in various environments. The properties generally characterize the unique and promising potential of CQDs in advanced scientific and technological applications.

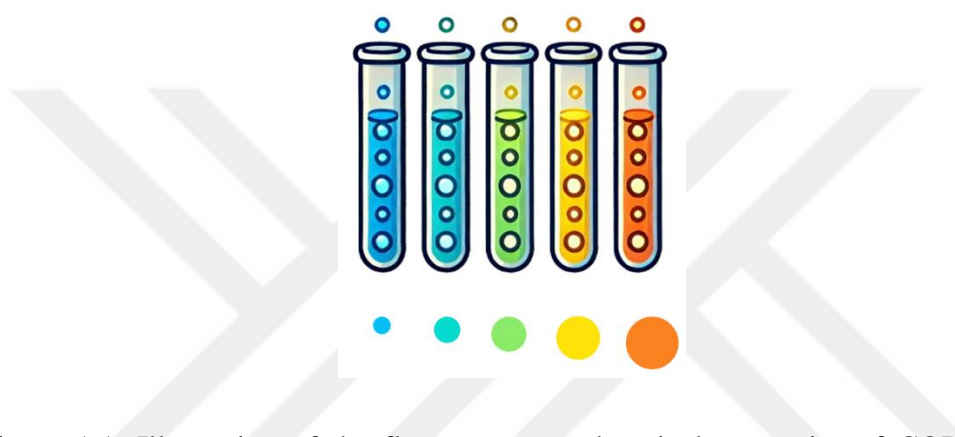


Figure 1.1: Illustration of the fluorescence and optical properties of CQDs with varying emission colors, highlighting their unique and tunable characteristics for diverse applications.

### 1.1.2 Properties and Applications of CQDs

CQDs have several unique properties that make them highly promising in different fields of science and technology. These include optical properties, chemical stability and surface functionalization, which together enable their applications in biosensing, bioimaging, energy storage, photocatalysis and drug delivery [7]. The variety applications of CQDs across scientific and technological domains are summarized in Figure 1.2.

## i. Optical Properties

The most remarkable feature of CQDs is their strong PL, which comes from a combination of the quantum confinement effect, surface state emissions and molecular fluorophores. One of the distinctive properties of CQDs is their excitation reliant emission, where the fluorescence wavelength can be changed by changing the excitation wavelength. This ability to do fluorescence allows CQDs to be utilized in a broad range of applications. In biosensing, CQDs are used for detecting biomolecules such as dopamine and serotonin, making use of their sensitivity and selectivity. In bioimaging, their non-toxic nature makes them ideal fluorescent checking for cellular imaging. In addition, CQDs serve as effective light absorbing catalysts in photocatalysis, particularly in environmental cleanup processes, showing off their ability to adapt in both biological and environmental domains [8].

## ii. Surface Functionalization

The surface functionalization of CQDs would let the QDs more versatile and reactive, the functionalization of CQDs could be done by hydroxyl, amino and carboxyl groups. These functional groups facilitate easy modification and conjugation with a variety of molecules. CQDs functionalized with targeting ligands can selectively bind to neurotransmitters like dopamine, serotonin. Furthermore the tailored surface chemistry of CQDs improves their water solubility and promotes efficient interactions with pollutants. These properties underline the adaptability of CQDs in various biomedical fields [9].

## iii. Chemical Stability and Biocompatibility

Different from metal based quantum dots, CQDs exhibit really great chemical and photostability under different environmental conditions. Further, their low cytotoxicity and biocompatibility make CQDs ideal for biomedical applications, particularly in vivo imaging and biosensing [5].

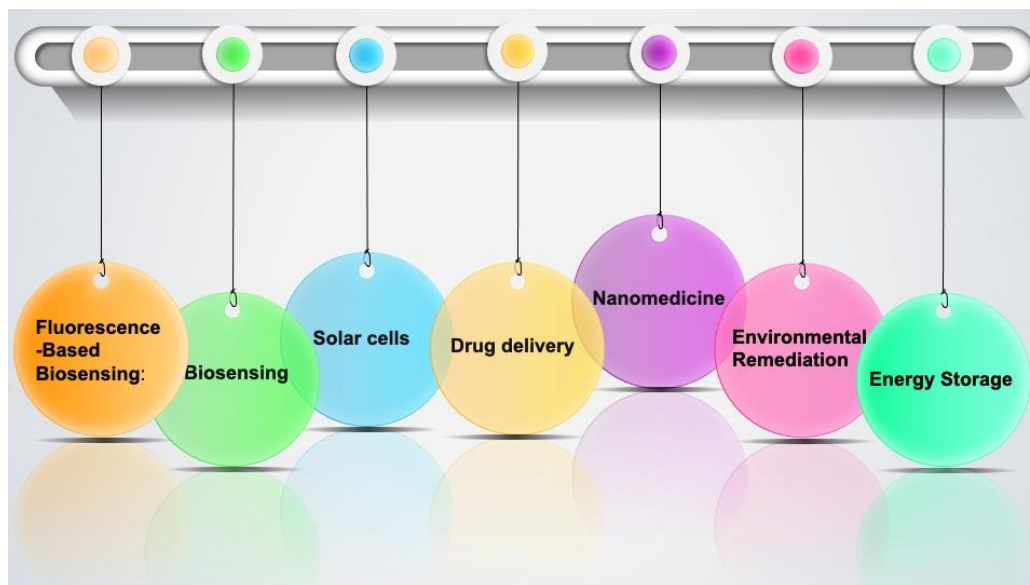


Figure 1.2 Overview of the diverse applications of CQDs in fields such as biosensing, solar cells, drug delivery, nanomedicine, environmental remediation and energy storage, highlighting their versatility and multifunctional potential.

CQDs are very important role in a number of progress applications due to their unique properties. In fluorescence based biosensing, CQDs perform as highly sensitive fluorescent probes enough to of detecting neurotransmitters such as dopamine and serotonin, as well as proteins like BSA. Their functionalization also allows for useful drug delivery, enabling the moving things of useful for agents to specific plans for within the human body. In the vastness of environmental remediation, CQDs serve as effective photocatalysts for degrading toxins in the like MB and MO under visible light. Moreover, their excellent conductivity and optical absorption properties make them good news candidates for energy storage applications, including solar cells, supercapacitors and power tools, showing off their ability to across scientific and industrial domains.

### 1.1.3 Comparison to Other Quantum Dots

CQDs offer numerous advantages over traditional quantum dots (e.g., CdTe, CdSe) and other carbon nanomaterials (e.g., graphene oxide, carbon nanotubes), as summarized in the table 1.1 below:

Table 1.1: The table highlights the superiority of CQDs in terms of safety, solubility and versatility, particularly for biomedical and environmental applications. This comparison emphasizes why CQDs have become a preferred nanomaterial for neurotransmitter detection and photocatalysis [8].

<b>Property</b>	<b>CQDs</b>	<b>Metal Based QDs</b>	<b>Carbon Nanotubes</b>
<b>Size</b>	2–10 nm	1–10 nm	1D nanostructures (length > $\mu\text{m}$ )
<b>Toxicity</b>	Low	High (contains heavy metals)	Moderate
<b>Optical Properties</b>	Tunable fluorescence, strong PL	Bright but toxic emissions	Limited fluorescence
<b>Solubility</b>	High (water soluble)	Low (requires modification)	Poor
<b>Biocompatibility</b>	Excellent	Poor	Moderate

<b>Applications</b>	Biosensing, photocatalysis, imaging	Imaging, photovoltaics	Electronics, composites
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## 1.2 Organic Waste Materials for CQD Synthesis

### 1.2.1 Watermelon Peels and Orange Peels as Precursors

Organic waste, particularly fruit and vegetable residues, has increasingly become a focal point in sustainable material research. As urbanization and agricultural activities expand globally, the production of organic waste continues to rise, presenting both environmental challenges and opportunities for resource utilization [10]. Fruit peels such as WP and OP are abundant and underutilized organic wastes that offer significant potential as carbon rich precursors for the synthesis of nanomaterials like CQDs [11].

As side effects of commonly used up fruits, WP and OP offer inexpensive and long term sources for the synthesis of CQDs. No matter their rich biological composition, WP, which make for 30–40% of the fruit's weight, are frequently thrown away as waste. In addition to cellulose, which is the main carbon origin required for the creation of CQDs, they also contain hemicellulose, lignin, and pectin, which add further organic and structural material. They are perfect Those who are for green synthesis techniques including MW and HT procedures because of their low cost and high carbon to hydrogen ratio. In addition to producing useful nanomaterials, repurposing WP lowers environmental damage caused by inappropriate waste disposal [12].

Similarly, OP, which comprises 40–50% of the fruit weight, is an abundant byproduct of fruit juice production. These exfoliants are abundant in cellulose, hemicellulose, pectin, essential oils, and flavonoids. These biomolecules facilitate the fabrication of functionalized CQDs and incorporate surface functional groups, including hydroxyl and carboxyl, derived from flavonoids and essential oils. These

functional groups facilitate the synthesis of CQDs with enhanced photoluminescence, enhanced aqueous solubility, and customized properties. The high carbon content and distinct chemical composition of OP make them a potential asset for green synthesis, transforming waste into valuable nanomaterials for many applications [13].

### 1.2.2 Advantages of Organic Waste for CQD Synthesis

An eco friendly and sustainable instead of for conventional techniques that rely on artificial chemicals is the synthesis of CQDs using organic waste materials. In besides to solving waste disposal issues, organic waste, such as WP and OP, is a renewable resource that cuts down environmental pollution, such as methane emissions, soil being dirty contamination, and landfill gathering[5]. It is a cost-effective precursor for large-scale CQD manufacturing due to its abundant availability at low or no cost, especially in areas with high agricultural waste [14]. Furthermore, cellulose, hemicellulose, and lignin—all naturally occurring carbon-based substances found in fruit peels—can be effectively carbonized to create CQDs without the need of costly or dangerous chemical precursors [15]. Organic waste contains surface functional groups (hydroxyl, carboxyl, and amino) that facilitate the synthesis of functionalized CQDs, improving their photoluminescence, water solubility, and selectivity for aims for molecules like dopamine [16]. Furthermore, by encouraging the circular economy where waste materials are effectively recovered and reused this green synthesis technique supports both environmental and economic sustainability, which is in line with global sustainability goals [17].

## 1.3 Synthesis Methods of CQDs

As shown in Figure 1.3, the synthesis of CQDs is a complex process comprising a different of approaches that can be broadly divided into top-down and bottom-up approaches. While bottom-up methods create carbon quantum dots from chemical precursors, top-down methods break down bulk carbon materials like graphite into nanoscale particles. In recent years, bottom-up methods have garnered a lot of interest, particularly those that are consistent with sustainable and green chemical concepts. Because of their ease of use, being affordable, and environmental friendliness, these techniques are recommended. Two well known methods that are

famous for their excellent efficiency and capacity to generate CQDs with carefully in control physicochemical features are MW synthesis and HT synthesis. These techniques are especially well suited for using organic waste as earlier steps, and they align with the thoughts of resource efficiency and sustainability [18].

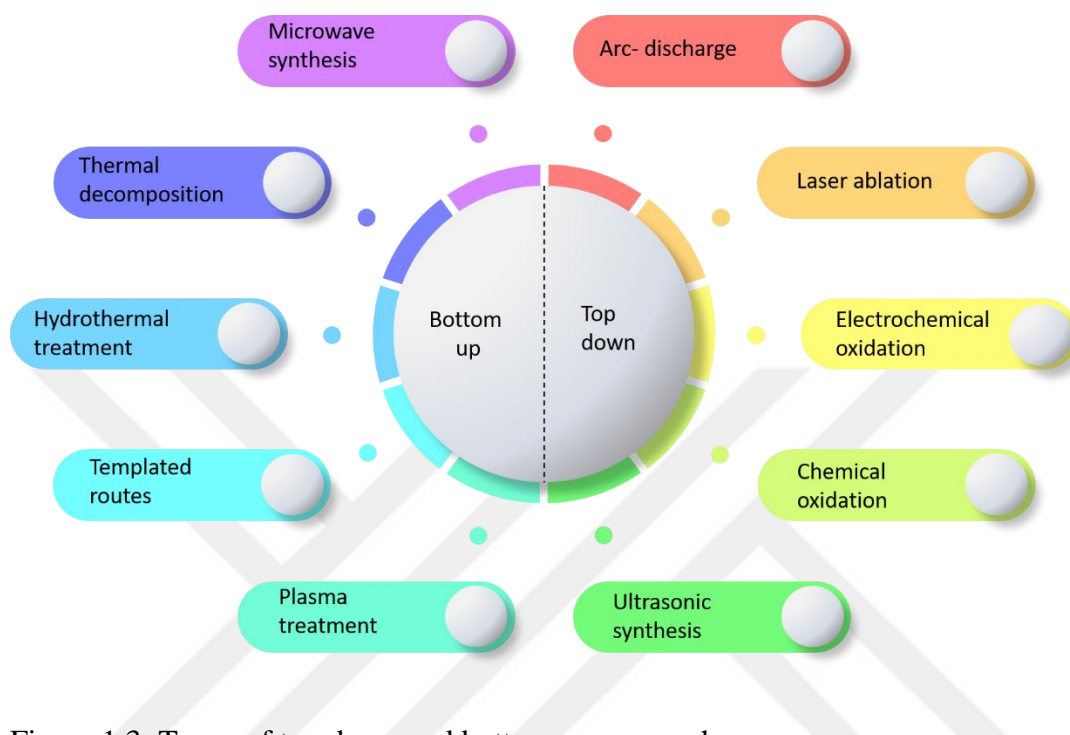


Figure 1.3: Types of top down and bottom up approaches

### 1.3.1 Microwave Assisted Synthesis

A bottom-up method called MW synthesis uses MW radiation to quickly and evenly heat carbon-rich precursors, showing ads their carbonization. A before to solution made from organic waste materials like WP or OP is most of prepared at the start of the procedure. To make a uniform, carbon rich solution, these Various parts are first dried, then crushed into a fine powder and dissolved in polar solvents like water. After that, the solution is exposed to MW irradiation for a short period of time, typically three minutes, with reaction temperatures regulated between 120°C and 200°C based on the MW's power settings. CQDs are created when the organic molecules undergo carbonization due to the quick and even heating that MW energy provides. Crucial surface functional groups like hydroxyl (-OH-) and carboxyl (-COOH) are maintained during this process, improving the CQDs' solubility and photoluminescent qualities. The solution is chilled after synthesis, centrifuged to get rid of bigger particles and contaminants, and then filtered to separate the CQDs for

additional analysis. This process has a number of benefits, such as quick synthesis that can be finished in a few minutes, energy efficiency because it uses MW heating, and a low environmental impact because it uses water as the solvent and calls for little chemical inputs. Moreover, MW synthesis is very scalable, which makes it appropriate for industrial applications and large-scale CQD production. This method has been especially effective in turning organic waste into valuable nanoparticles, demonstrating a sustainable approach to the development of nanotechnology [19].

### **1.3.2 Hydrothermal Synthesis**

Another well-known bottom-up method is HT synthesis, which depends on carbonizing organic matter in a sealed high-pressure packing box, mostly a stainless steel autoclave lined with Teflon. In order to obtain homogeneity, organic waste materials, such as fruit peels, must first be processed by washing, drying, and grinding before being broken up in water or another solvent to create a precursor solution. The autoclave, which is sealed to preserve the required high pressure environment, is subsequently filled with the precursor solution. The autoclave is heated to temperatures between 150°C and 200°C for periods of time that usually last five hours. The organic molecules go through processes of dehydration, carbonization, and nucleation under these conditions, producing CQDs with consistent size and shape. After the reaction is finished, the autoclave is allowed to cool to ambient temperature, and the resultant solution is centrifuged to remove any remaining contaminants. For later usage, the supernatant—which contains the CQDs—is gathered and filtered. The capacity of HT synthesis to yield very much homogeneous and evenly distributed nanoparticles makes it especially beneficial. By using water as the solvent and reaction medium, the technique does not require harsh chemical reagents, making it environmentally safe. Furthermore, the freedom to add dopants or surface modifiers during the reaction provided by HT synthesis allows CQDs to be functionalized for particular uses, for example drug delivery, photocatalysis, and biosensing. Because it can handle higher volumes of precursors while keeping up product uniformity and quality, its scaling up further emphasizes its appropriateness for business applications [3]. Table 1.2 lists the differences and similarities between MW and HT synthesis.

Table1.2: Comparison with MW Synthesis and HT synthesis methods

<b>Parameter</b>	<b>Microwave Assisted</b>	<b>Hydrothermal</b>
<b>Reaction Time</b>	3 min	5h
<b>Temperature Control</b>	Moderate, easily adjustable	High, controlled via autoclave
<b>Energy Efficiency</b>	High	Moderate
<b>Product Uniformity</b>	Good	Good
<b>Scalability</b>	High	High

## 1.4 Characterization of CQDs

The comprehensive characterization of CQDs synthesized from WP and OP was conducted using a series of advanced analytical techniques to thoroughly confirm their optical, structural, morphological and surface properties, ensuring their suitability for various applications. First, UV Vis spectroscopy was utilized to investigate the optical absorption characteristics of the synthesized CQDs. This analysis revealed a prominent absorption peak at approximately 270 nm, indicative of the presence of graphitic domains, which are a hallmark of CQDs. Additionally, broad absorption shoulders observed in the spectra confirmed the successful surface functionalization of the CQDs and highlighted the structural heterogeneity of these nanomaterials. These features are directly linked to the unique electronic transitions occurring within the  $sp^2$  hybridized carbon core and surface functional groups, such as COOH and OH, further validating the formation of CQDs.

The findings underscored the quantum confinement effect, which plays a crucial role in the unique photoluminescent properties of CQDs and is essential for their performance in optoelectronic and sensing applications. DLS was performed to determine the hydrodynamic diameter of the CQDs in colloidal solution, revealing an average size of 1–4 nm. The low Polydispersity Index obtained from the DLS measurements indicated a narrow size distribution, signifying the uniformity of the synthesized CQDs. Moreover, the zeta potential measurements, which ranged from 35 to 40 mV, demonstrated excellent colloidal stability. This high stability was attributed to the negatively charged surface functional groups, such as carboxyl groups, which prevent aggregation and ensure the suitability of CQDs for various biological and chemical applications.

Lastly, PL spectroscopy was conducted to analyze the optical emission properties of the CQDs. The PL analysis revealed strong fluorescence emission in the visible range (~450–500 nm) when excited at different wavelengths, confirming the excitation dependent behavior of the CQDs. This behavior is a result of surface defects, size heterogeneity and the quantum confinement effect. The high PL intensity demonstrated the excellent optical quality of the synthesized CQDs, making them highly suitable for advanced applications, such as fluorescence based sensors for detecting dopamine and other neurotransmitters.

Overall, the thorough characterization of CQDs using UV Vis spectroscopy, DLS and PL analysis not only confirmed the successful synthesis of these nanomaterials but also highlighted their promising properties for diverse applications. These include photocatalysis for environmental remediation, fluorescence imaging and the selective detection of neurotransmitters such as dopamine. The results of this study underscore the versatility and potential of CQDs synthesized from organic waste materials, paving the way for their use in cutting edge technologies and sustainable solutions.

## 1.5 Applications of CQDs

CQDs have emerged as versatile nanomaterials due to their unique optical, electronic and chemical properties, such as strong PL, biocompatibility and excellent water solubility. These properties make CQDs suitable for a wide range of

applications in fields such as biomedicine, environmental remediation, catalysis and sensors. This section highlights the major applications of CQDs, with a particular focus on photocatalysis, dye degradation and biosensing of neurotransmitters like dopamine [20].

### 1.5.1 Photocatalytic Applications

#### Principle of Photocatalysis

Photocatalysis involves the use of light energy to drive chemical reactions, primarily for the degradation of organic pollutants or water splitting. CQDs are effective photocatalysts because of their broad light absorption (UV to visible range), high surface area and ability to facilitate electron transfer [21].

When CQDs are exposed to light, photoexcited electrons ( $e^-$ ) move from the valence band to the conduction band, leaving behind positive holes ( $h^+$ ). These electrons and holes generate reactive oxygen species (ROS), such as hydroxyl radicals (OH) and superoxide anions ( $O_2^-$ ), which degrade pollutants or facilitate other reactions.

#### Photocatalytic Applications of CQDs

- Environmental Remediation: CQDs have been widely used to degrade organic dyes and pollutants in wastewater.
- Water Splitting: CQDs act as photocatalysts for splitting water molecules into hydrogen and oxygen for renewable energy production.
- Energy Conversion: CQDs can enhance the performance of solar cells by improving light absorption and electron transport efficiency.

In this study, CQDs synthesized from WP and OP were tested for their photocatalytic ability to degrade MB and MO dyes. The results demonstrated that CQDs efficiently degrade dyes under visible light, showing their potential for water treatment and environmental applications [22].

### 1.5.2 Environmental Remediation of Dyes

#### Environmental Concerns of Synthetic Dyes

Synthetic dyes, such as MB and MO, are widely used in textile, printing and paper industries. These dyes are toxic, non biodegradable and can cause significant harm to aquatic ecosystems and human health if discharged untreated into water sources.

Conventional methods for dye removal, such as coagulation and adsorption are often inefficient or energy intensive. Therefore, photocatalysis using CQDs offers a sustainable and efficient solution for degrading harmful dyes into harmless byproducts like carbon dioxide (CO<sub>2</sub>) and water [23].

### Role of CQDs in Dye Degradation

- **Light Absorption:** CQDs absorb visible light and generate electron hole pairs that initiate the degradation process.
- **ROS:** CQDs produce ROS that break the chemical bonds of dye molecules.
- **Surface Area:** The high surface area of CQDs enhances dye adsorption, improving photocatalytic efficiency.

In this study, CQDs were applied for the degradation of:

1. MB: A cationic dye widely used in textiles.
2. MO: An anionic dye commonly used in dyeing and printing.

Experimental results demonstrated that CQDs effectively degrade these dyes under light irradiation, highlighting their potential for wastewater treatment [24].

## 1.5.3 Detection of Neurotransmitters

### Importance of Neurotransmitter Detection

Neurotransmitters are essential chemical messengers in the human nervous system. Abnormal levels of neurotransmitters like dopamine and serotonin are linked to neurological disorders, including Parkinsons disease, depression and schizophrenia. The ability to detect neurotransmitters quickly, accurately and selectively is critical for medical diagnostics and monitoring neurological health.

### CQDs as Fluorescence Sensors for Neurotransmitters

CQDs have emerged as excellent fluorescence based sensors for neurotransmitter detection due to the following properties:

- PL: CQDs exhibit stable and tunable fluorescence properties.
- Surface Functionalization: Functional groups on CQD surfaces allow for specific interactions with target molecules like dopamine.
- Sensitivity: CQDs can detect neurotransmitters at very low concentrations due to their fluorescence quenching mechanisms [25].

### Mechanism of Dopamine Detection

Dopamine interacts with CQDs through an electron transfer process or oxidation reaction, leading to fluorescence quenching of CQDs. The decrease in fluorescence intensity is proportional to dopamine concentration, enabling quantitative detection [26].

The detection mechanism is described as follows:



The oxidized dopamine quinone interacts with CQDs, quenching their fluorescence [27].

### Selectivity Studies Using BSA and Serotonin

To confirm the selectivity of CQDs for dopamine detection, control experiments were conducted using BSA and serotonin. While serotonin and BSA showed minimal interaction with CQDs, dopamine exhibited significant fluorescence quenching, proving the selectivity of CQDs for dopamine detection [28].

### Applications of Neurotransmitter Detection

- Medical Diagnostics: Monitoring dopamine levels for early detection of Parkinson's disease and schizophrenia [20].
- Biomedical Research: Investigating the role of neurotransmitters in neurodegenerative disorders [29].

## 1.6 Dopamine Detection Using CQDs

Dopamine is a critical neurotransmitter involved in various physiological functions, including motor control, mood regulation and cognitive processes. Abnormal levels of dopamine are linked to neurological and psychiatric disorders, such as Parkinsons disease, schizophrenia and depression. Accurate and selective detection of dopamine is essential for understanding its role in biological systems and for diagnosing related disorders. CQDs have emerged as effective tools for dopamine detection due to their strong photoluminescence, biocompatibility and ability to interact selectively with dopamine molecules. This section discusses the biological significance of dopamine and the fluorescence based mechanism by which CQDs detect dopamine [25].

### 1.6.1 Role of Dopamine in Biological Systems

#### I. Dopamine's Functions in the Human Body

Dopamine serves as a critical neurotransmitter in the central nervous system and peripheral nervous system. Its primary functions include:

- **Motor Control:** Dopamine regulates voluntary movement by transmitting signals between the basal ganglia and motor cortex.
- **Mood Regulation:** Dopamine contributes to the reward system, influencing pleasure, motivation and emotional well being.
- **Cognitive Function:** It plays a role in learning, attention and decision making processes.
- **Endocrine Regulation:** Dopamine acts on the hypothalamus to regulate hormone secretion, such as prolactin [30].

#### II. Disorders Associated with Dopamine Dysregulation

Abnormal dopamine levels can lead to a variety of medical conditions, including:

- **Parkinson's Disease:** A neurodegenerative disorder caused by the depletion of dopamine in the substantia nigra, resulting in tremors, rigidity and bradykinesia.

- Schizophrenia: Elevated dopamine levels in specific brain regions contribute to hallucinations, delusions and cognitive impairments.
- Depression: Low dopamine activity is linked to symptoms such as anhedonia, fatigue and lack of motivation.
- Addiction: Dopamine dysregulation reinforces reward seeking behaviors, leading to substance dependence.

The ability to detect and quantify dopamine accurately is crucial for diagnosing these disorders and monitoring therapeutic interventions [31].

## 1.6.2 Mechanism of Dopamine Detection with CQDs

### I. Fluorescence Quenching Mechanism

CQDs exhibit strong fluorescence properties, which are sensitive to the presence of dopamine. The detection mechanism primarily involves fluorescence quenching, a process where the interaction between dopamine and CQDs reduces the fluorescence intensity [32]. The main quenching mechanisms are:

- Electron Transfer: Dopamine, in its oxidized form (dopamine quinone), can accept electrons from the excited state CQDs, resulting in fluorescence quenching.
- Energy Transfer: The energy from the excited CQDs is transferred to dopamine molecules, causing a decrease in light emission [33].

The oxidation reaction of dopamine is expressed as:



This reaction produces dopamine quinone, which interacts with CQDs and leads to measurable fluorescence changes [29].

### II. Role of Surface Functional Groups on CQDs

The presence of functional groups such as hydroxyl (OH) and carboxyl (COOH) on the surface of CQDs facilitates specific interactions with dopamine molecules through:

- **Hydrogen Bonding:** Dopamines hydroxyl groups form hydrogen bonds with CQD surface groups.
- **Electrostatic Interactions:** The amino group in dopamine interacts with negatively charged functional groups on CQDs [34].

These interactions enhance the selectivity of CQDs for dopamine detection while minimizing interference from other biomolecules.

## II. Selectivity Studies

Selectivity is a critical factor in dopamine detection, as other biomolecules such as serotonin and proteins like BSA may interfere. Control experiments with serotonin and BSA demonstrated:

- Significant fluorescence quenching with dopamine.
- Minimal quenching with serotonin and BSA, confirming the selectivity of CQDs for dopamine detection [35].

### 1.7 Serotonin Detection Using CQDs

Serotonin (5 hydroxytryptamine or 5 HT) is an essential neurotransmitter that regulates numerous physiological and psychological processes. Abnormal levels of serotonin are associated with various mental health and neurological disorders, such as depression, anxiety and serotonin syndrome. The detection of serotonin is crucial for understanding its role in biological systems and for clinical diagnostics [36].

CQDs have demonstrated significant potential in the fluorescence based detection of serotonin due to their sensitivity, photoluminescence properties and ability to interact with biomolecules. This section explores the biological role of serotonin and the use of CQDs in its detection [37].

#### 1.7.1 Role of Serotonin in Biological Systems

##### I. Role of Serotonin in Biological Systems

Serotonin is a key neurotransmitter synthesized in the brain and gastrointestinal tract. It influences a wide range of physiological processes, including:

- **Mood Regulation:** Serotonin is often referred to as the happiness chemical due to its role in stabilizing mood and promoting feelings of well being [15].
- **Sleep Wake Cycle:** It regulates circadian rhythms and facilitates sleep onset by being converted into melatonin.
- **Appetite and Digestion:** Serotonin affects appetite and controls bowel movements in the gastrointestinal tract [31].
- **Cognition and Memory:** It plays a role in learning, memory retention and decision making processes.
- **Cardiovascular and Muscular Systems:** Serotonin influences the contraction of smooth muscles and regulates blood vessel tone [38].

## II. Disorders Linked to Serotonin Dysregulation

Imbalances in serotonin levels are associated with several disorders, including:

- **Depression:** Low serotonin levels are a major contributing factor to mood disorders.
- **Anxiety Disorders:** Serotonin dysfunction can lead to heightened states of fear and worry [39].
- **Serotonin Syndrome:** A potentially life threatening condition caused by excessive serotonin levels, often triggered by drug interactions.
- **Irritable Bowel Syndrome (IBS):** Serotonin dysregulation in the gut contributes to abnormal bowel function [40].

Given the importance of serotonin in both mental and physical health, the ability to detect serotonin accurately and efficiently is crucial for clinical applications.

### 1.7.2 Testing and Observations for Serotonin Detection

#### I. Role of CQDs in Serotonin Detection

CQDs are well suited for serotonin detection due to their strong photoluminescence and ability to interact with biomolecules. The mechanism of detection relies on the quenching of CQD fluorescence in the presence of serotonin, similar to dopamine detection [32]. The main steps include:

- Interaction: Serotonin molecules interact with the surface functional groups (e.g., COOH, OH) on CQDs via hydrogen bonding and electrostatic interactions.
- Quenching: The interaction alters the electronic structure of CQDs, leading to fluorescence quenching or enhancement, depending on the specific reaction conditions.
- Quantification: The change in fluorescence intensity is proportional to serotonin concentration, enabling quantitative analysis [33].

## II. Testing Protocol

In this study, serotonin detection was evaluated using CQDs synthesized from WP and OP. The testing procedure involved:

- Preparation: Aqueous solutions of CQDs and serotonin were prepared.
- Fluorescence Measurement: The fluorescence intensity of CQDs was measured before and after the addition of serotonin at varying concentrations.
- Control Studies: To assess selectivity, control experiments were conducted using dopamine and BSA under identical conditions [25].

## III. Observations

- Fluorescence Response: The CQDs exhibited a decrease in fluorescence intensity upon the addition of serotonin, confirming the interaction between CQDs and serotonin.
- Concentration Dependency: The quenching effect was found to be proportional to serotonin concentration, with a linear relationship observed within a specific range.
- Selectivity: While CQDs showed a fluorescence response to serotonin, the quenching effect was less pronounced compared to dopamine. This result demonstrated that CQDs have a higher affinity for dopamine, highlighting their selective sensing capability [38].

## IV. Comparison with Dopamine Detection

A comparative study of serotonin and dopamine detection revealed:

- Dopamine caused a more significant fluorescence quenching effect, indicating stronger interaction with CQDs.
- Serotonin exhibited weaker quenching, likely due to differences in molecular structure and functional group interactions [41].

The selectivity results validate the potential of CQDs for differentiating between neurotransmitters, making them versatile tools for biosensing applications

## 1.8 BSA and Selectivity Studies

BSA is a well characterized protein that serves as a model molecule in biochemical and biophysical studies. In the context of biosensors, BSA is often used to evaluate the selectivity of sensing platforms. Since biomolecules such as proteins, neurotransmitters and ions coexist in biological systems, it is critical to ensure that sensors selectively interact with target molecules without interference from non specific interactions.

CQDs due to their functionalized surfaces, can exhibit selective fluorescence quenching when exposed to specific target molecules. In this study, BSA was used as a control molecule to evaluate the selectivity of CQDs for detecting dopamine and serotonin [42].

### 1.8.1 Role of BSA in Selectivity Testing

#### I. Purpose of Using BSA

BSA is widely used as a standard protein in selectivity studies because:

- **Abundance in Biological Systems:** Albumins are the most abundant proteins in blood plasma, making them relevant for assessing real world sensor performance.
- **Non Specific Binding:** BSA can bind to a variety of molecules due to its large size and diverse binding sites, making it an ideal control molecule to test non specific interactions.

- Ease of Availability and Stability: BSA is inexpensive, highly stable and easily available, ensuring reproducibility in experiments [43].

In this study, BSA was used to:

1. Assess whether the fluorescence of CQDs is quenched non specifically by proteins.
2. Compare the fluorescence response of CQDs to dopamine, serotonin and BSA.
3. Validate the selective interaction of CQDs with neurotransmitters over proteins.

## II. Selectivity Testing Protocol

To evaluate selectivity, the fluorescence intensity of CQDs was measured under the following conditions:

1. Control: CQDs alone in an aqueous solution.
2. Target Molecules: CQDs in the presence of dopamine and serotonin.
3. Control Molecule: CQDs in the presence of BSA [44].

The testing involved adding fixed concentrations of dopamine, serotonin and BSA to separate CQD solutions and recording the fluorescence intensity changes.

### 1.8.2 Results and Observations of BSA Interaction

#### I. Fluorescence Response of CQDs with BSA

The addition of BSA to the CQD solution resulted in minimal changes in fluorescence intensity. This observation suggests that:

- CQDs exhibit weak or negligible non specific interactions with BSA.
- The fluorescence quenching observed with dopamine and serotonin is likely due to specific interactions rather than non specific binding.

#### II. Comparison with Dopamine and Serotonin

The fluorescence quenching behavior of CQDs was analyzed for all three molecules (dopamine, serotonin and BSA):

- Dopamine: Induced significant fluorescence quenching due to its strong electron transfer and oxidation interactions with CQDs.
- Serotonin: Induced moderate fluorescence quenching, attributed to weaker interactions compared to dopamine.
- BSA: Caused negligible fluorescence quenching, confirming that CQDs do not interact strongly with proteins [43], [44].

### III. Selectivity Validation

The results demonstrated that CQDs have a higher selectivity for dopamine and serotonin over BSA. This selectivity is attributed to:

- Functional Group Interactions: Dopamine and serotonin possess functional groups (e.g., hydroxyl, amine) that interact specifically with the surface groups of CQDs.
- Size and Structure: BSA is a large protein, making it sterically hindered from forming effective interactions with the small sized CQDs [45].

### IV. Implications for Biosensing Applications

The ability of CQDs to differentiate between small biomolecules (dopamine, serotonin) and larger proteins (BSA) highlights their potential for use in selective biosensors. This selectivity ensures accurate detection of neurotransmitters in complex biological environments.

## 1.9 Comparison of Neurotransmitter Selectivity (Dopamine vs. Serotonin)

The ability of CQDs to detect specific neurotransmitters is essential for their application in biosensors. Among the tested neurotransmitters, dopamine and serotonin are chemically similar but differ in their interactions with CQDs. This section compares the selectivity of CQDs toward these neurotransmitters, highlighting the underlying mechanisms and experimental observations [46].

### 1.9.1 Differences in Chemical Structures

The chemical structures of dopamine and serotonin play a crucial role in their interaction with CQDs:

- Dopamine: Contains a catechol group (benzene ring with two hydroxyl groups) and an amino group. The catechol structure facilitates strong electron transfer and surface binding interactions with CQDs.
- Serotonin: Contains an indole ring and a hydroxyl group, making it less reactive toward CQDs compared to dopamine due to differences in electron density and bonding sites [47].

### 1.9.2 Fluorescence Quenching Observations

Experiments showed that:

- Dopamine induced significant fluorescence quenching of CQDs. This is attributed to its ability to undergo oxidation to dopamine quinone, which participates in efficient electron transfer with CQDs.
- Serotonin caused moderate fluorescence quenching, likely due to weaker interactions and the absence of a catechol structure [35].

### 1.9.3 Selectivity Results

The selectivity of CQDs was validated through:

1. Quenching Efficiency: Dopamine exhibited higher quenching efficiency compared to serotonin, indicating stronger and more specific interactions with CQDs.
2. Fluorescence Intensity Analysis: A greater reduction in fluorescence intensity was observed for dopamine, confirming its preferential interaction with CQDs.
3. Linear Relationship: Dopamine displayed a more consistent linear relationship between concentration and quenching, making it easier to quantify [20].

### 1.9.4 Implications for Biosensing

The higher selectivity of CQDs for dopamine over serotonin has significant implications for biosensing applications:

- It demonstrates that CQDs can act as reliable and selective sensors for dopamine detection in complex biological systems.
- The differentiation between dopamine and serotonin highlights the potential of CQDs for multiplexed sensing of multiple neurotransmitters in clinical diagnostics [25].

## 1.10 Significance and Objectives of the Study

The synthesis and application of CQDs from organic waste materials for neurotransmitter detection represent a significant advancement in nanotechnology, sustainability and biomedical research. This study addresses critical challenges in material synthesis, environmental sustainability and biosensing.

### 1.10.1 Significance of the Study

#### I. Environmental Impact

The use of organic waste materials such as WP and OP aligns with global sustainability goals by:

- **Recycling Waste:** Reducing the environmental burden of organic waste disposal.
- **Promoting Green Synthesis:** Avoiding hazardous chemicals and energy intensive processes [32].

#### II. Biomedical Applications

CQDs offer a sensitive and selective platform for detecting neurotransmitters, which is essential for diagnosing and monitoring neurological disorders. The fluorescence based detection method provides:

- **Rapid Results:** Fast response times compared to traditional techniques.
- **High Sensitivity:** Detection of neurotransmitters at nanomolar concentrations.

- Selectivity: Differentiation between structurally similar molecules like dopamine and serotonin [30].

### III. Economic Feasibility

The use of inexpensive organic waste precursors makes CQD synthesis cost effective, paving the way for scalable production and widespread application.

#### 1.10.2 Objectives of the Study

The primary objectives of this study are:

##### I. Synthesis of CQDs from Organic Waste Materials

To develop an eco friendly synthesis approach for CQDs using WP and OP as carbon precursors through MW and HT methods [48].

##### II. Characterization of CQDs

To thoroughly characterize the synthesized CQDs using analytical techniques, including:

- UV Vis spectroscopy
- DLS and Zeta Potential analysis
- PL

##### III. Evaluation of CQD Applications

To evaluate the applicability of CQDs in:

- Dopamine Detection: Testing sensitivity, selectivity and fluorescence quenching mechanisms.
- Serotonin Detection: Assessing the response of CQDs to serotonin and comparing it to dopamine.
- Photocatalytic Degradation: Demonstrating the efficiency of CQDs in degrading dyes like methylene blue and methyl orange.

##### IV. Selectivity Testing Using BSA

To confirm the specificity of CQDs for neurotransmitters by testing their interaction with BSA as a control molecule [49].

## V. Advancing Biosensor Technologies

To demonstrate the potential of CQDs as biosensors for neurotransmitters, contributing to advancements in diagnostics and nanotechnology.

# Chapter 2

## 2. Materials and Methods

In this chapter, the thesis materials, instruments and experimental procedures are listed as follows;

### 2.1 Materials

The materials for this research include organic waste sources for CQD synthesis, as well as essential laboratory chemicals and reagents for CQD characterization and neurotransmitter detection studies.

#### 2.1.1 Organic Waste Materials:

WP: Used as a primary carbon source, WP contain abundant organic compounds suitable for CQD synthesis. Their high water content and natural biodegradability make them ideal for green chemistry applications [50].



Figure 2.1: Watermelon peels

OP: Similar to WP, OP serve as an effective carbon source due to their high cellulose and organic acid content, which facilitates efficient CQD formation and sustainability in synthesis [13].

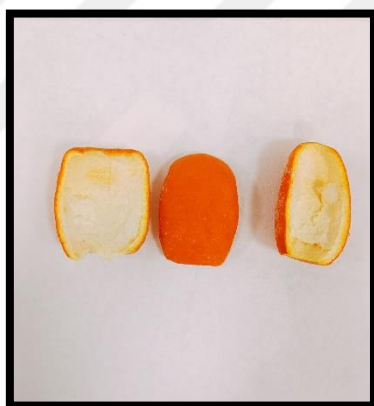


Figure 2.2: Orange peels

### 2.1.2 Chemicals and Solvents:

Distilled Water: Used as a solvent for solution preparation, reagent dilution and washing to maintain purity and prevent contamination throughout synthesis and testing.

Ethanol: Acts as a solvent and a cleaning agent. Ethanol supports CQD dispersion and helps control reaction conditions by minimizing oxygen exposure.

Nitric Acid (HNO<sub>3</sub>): Employed for adjusting pH levels and surface functionalization of CQDs, which can enhance CQD stability and reactivity.

Sodium Hydroxide (NaOH): Used to adjust pH levels and control CQD surface charge, aiding in stability and promoting effective dispersion in solutions.

### 2.1.3 Laboratory Reagents and Analytical Standards:

Dopamine and Serotonin Standard Solutions: Dopamine and serotonin are key neurotransmitters targeted in detection studies, allowing calibration and accuracy in selectivity and sensitivity tests. Their detection capabilities are tested to establish the CQDs biochemical sensing applications.

BSA is used as a non target molecule in selectivity tests, helping to demonstrate the CQDs specificity by acting as a control in dopamine and serotonin detection.

MB and Methyl MO: These dyes are model pollutants for photocatalytic degradation experiments, providing a basis to evaluate the environmental applications of CQDs in degrading harmful contaminants

## 2.2 Instruments

The synthesis and characterization of CQDs in this study were conducted using a variety of instruments. A home type microwave (SAMSUNG MS23F300E) was employed for MW synthesis, providing rapid heating for the CQD formation from organic waste materials. A centrifuge (Hettich Zentrifugen Universal 320) was used for separating and purifying the nanoparticles, while a freeze dryer (BIOBASE Lyophilizator) removed residual solvents and water. A rotary evaporator (BUTCHI) concentrated the CQD solution and an ultrasonic bath (Elmasonic) ensured uniform mixing during the synthesis process. The hotplate (IKA C MAG HP 10) was used for heating chemical reactions and the UV Visible Spectrophotometer (Thermo Scientific Evolution 201) measured the absorbance of the CQDs in the range of 250 600 nm. DLS and Zeta Potential analysis (Anton Paar Litesizer 500) were utilized to determine the size, size distribution and surface charge of the CQDs. FT IR Spectroscopy (Thermo Scientific Nicolet IS50 FT IR) provided structural insights

by identifying functional groups on the CQD surface, while a handheld UV lamp (UVGL 58) was used for fluorescence tests. Additionally, the Edinburgh Instruments FS5 Spectrofluorometer was employed for detailed photoluminescence analysis of the CQDs, crucial for evaluating their optical properties. These instruments were critical for evaluating the synthesis, optical properties and surface characteristics of the CQDs, essential for their applications in biochemical sensing and environmental remediation.

## 2.3 Methods

### 2.3.1 Preparation of Organic Waste Extract

The preparation of organic waste extract was carried out using WP and OP as the primary sources as it written in table 2.1. The peels were initially washed thoroughly with deionized water to eliminate any surface contaminants. After cleaning, the peels were cut into small pieces and dried in an oven at 60–80°C for 24–48 hours to remove all moisture.

Once completely dried, the peels were ground into a fine powder using a laboratory grade grinder. The powder was sieved to ensure uniform particle size, which is critical for consistent extraction. A specific amount of the powdered material was then dispersed in deionized water to form a slurry, which was utilized in the subsequent carbonization process for the synthesis of CQDs. This prepared extract was stored at 4°C for further synthesis steps [51].

Table 2.1: synthesized CQDs using different organic materials

<b>Fruit Used</b>	<b>Waste</b>	<b>CQDs Size (nm)</b>	<b>Synthesis Method</b>	<b>Application</b>	<b>Reference</b>
Banana Peel		3 to 6	Hydrothermal	energy storage	[52]
banana peel		5	hydrothermal	Bioimaging	[53]
Lemon Juice		4	hydrothermal	optoelectronics and bioimaging	[54]

Coconut Shell	10	Hydrothermal	Antibacterial Activity	[55]
Mango Peel	40-60	classical method	Water soluble and fluorescent	[56]
papaya seeds	1.4	microwave-assisted	selective detection of Fe <sup>3+</sup> ions	[57]
Banana peels	1.4	microwave-assisted	detection of H <sub>2</sub> O <sub>2</sub> and glucose	[58]
Ficus religiosa tree	7.4	microwave-assisted	drug-resistant bacterial strains.	[59]
Watermelon peel	2.4	Microwave-assisted	Photocatalysis	This study
Orange peel	3.1	Microwave-assisted	Photocatalysis	This study

### 2.3.2 Synthesis of CQDs

#### I. Microwave Assisted Synthesis of CQDs

For the preparation of the organic waste extract used in the synthesis of CQDs, different procedures were followed for the MW synthesis methods to optimize the extraction process and prepare the organic material for carbonization. The general process involved the collection, cleaning, drying and extraction of the organic waste material, which consisted of WP and OP [48].



Figure2.3: Microwave

## Preparation for Microwave Synthesis:

For the MW synthesis, WP and OP were first collected and thoroughly washed with distilled water to remove any impurities. The cleaned peels were then subjected to a freeze drying process to ensure that all moisture was completely removed. Freeze drying is an effective method for preserving the structural integrity of organic material while removing water content, making it ideal for achieving a dry, powdery consistency in the peels. After freeze drying, the dried peels were finely ground using a mortar and pestle to produce a fine powder. This powder was subsequently soaked in distilled water for 24 hours to allow the extraction of soluble compounds, which contribute to the formation of functionalized CQDs.

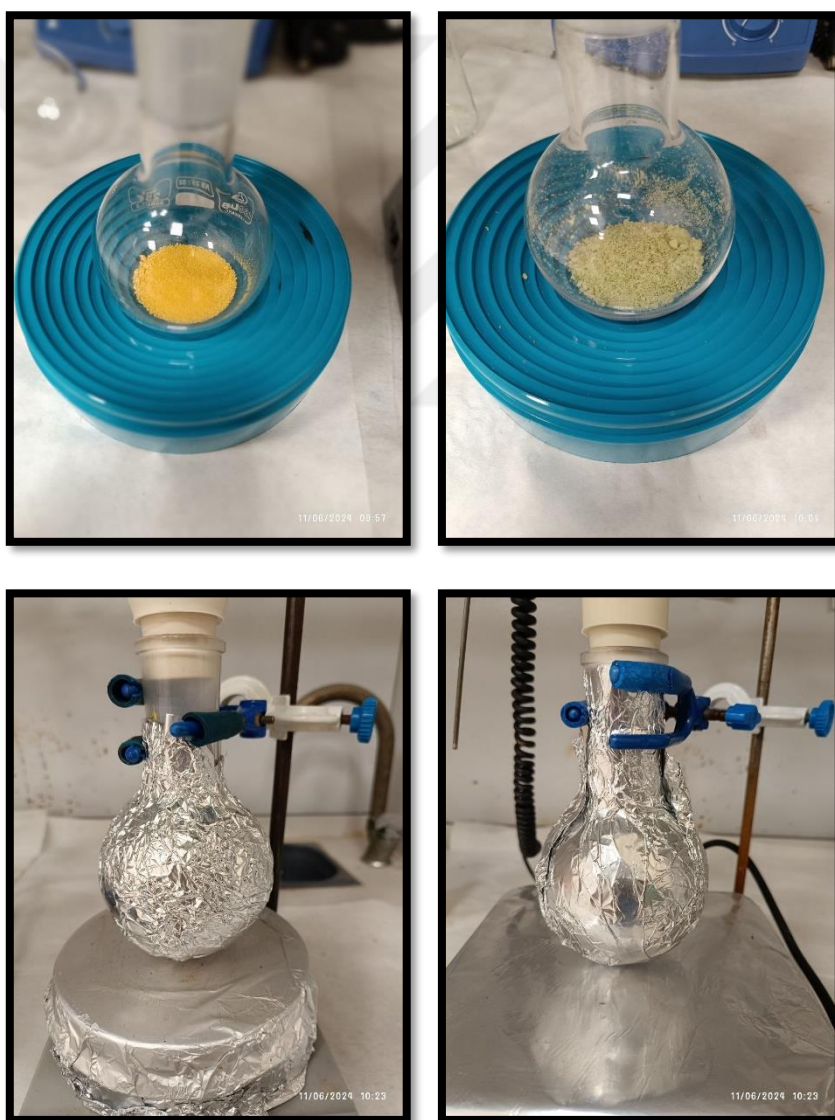


Figure 2.4: Preparation the WP and OP extract

After the soaking period, the mixture was filtered using filter paper to remove any solid residues, resulting in a clear organic extract rich in bioactive compounds.

Specifically, 10 mL of the extract was placed directly into an Erlenmeyer flask and irradiated in a home type MW for 3 minutes at 800W. The MW method is especially effective for CQD production because MW provide direct, uniform heating by generating an oscillating electromagnetic field. This field causes polar molecules within the organic extract to rotate rapidly, creating frictional heating throughout the solution. This rapid, uniform heating promotes efficient carbonization of the organic material, leading to the formation of CQDs in a matter of minutes [49].

During the brief reaction time, the organic compounds undergo dehydration and condensation, resulting in the carbonization of the precursor material and the formation of carbon based nanostructures. As the organic molecules are broken down, carbon atoms reorganize into small, graphitic or amorphous cores that form the basis of CQDs. Additionally, oxygen, nitrogen and other elements present in the organic waste contribute functional groups such as hydroxyl ( OH), carboxyl ( COOH) and amine ( NH<sub>2</sub>) to the surface of the CQDs. These functional groups enhance the stability, water solubility and fluorescence properties of the CQDs, making them suitable for applications like sensing and imaging.

After MW treatment, the CQD solution was allowed to cool to room temperature to prevent any thermal degradation of the synthesized CQDs. Following this cooling step, the CQDs were purified to remove any remaining larger particles or impurities. Instead of centrifugation, a syringe filter with a 0.22 μm pore size was used to filter the solution. This syringe filter was essential in ensuring that only nanoparticles smaller than the pore size passed through, producing a homogenous CQD solution free from unwanted particulate matter. Filtering with a syringe filter also offers a more controlled and precise purification method, particularly suited for small volume samples, ensuring consistency and reproducibility in the CQD product [60].



Figure 2.5: Syringe filter with a 0.22  $\mu\text{m}$

The filtered CQD solution was then stored at 4°C to preserve its stability, preventing potential aggregation or degradation before further use in characterization and application experiments. This streamlined MW synthesis process, combined with efficient filtration, enables the production of CQDs in a rapid, cost effective and reproducible manner.

## II. Hydrothermal Synthesis of CQDs

In the HT synthesis process, the preparation of the organic waste extract differed slightly due to the requirements of the HT method. After washing the WP and OP with distilled water, they were dried in an oven at 60°C initially to remove excess moisture and then carbonized at 220°C for 4 hours to initiate partial decomposition and carbonization. This step at 220°C encourages the breakdown of complex organic molecules and initiates the formation of carbon rich precursors, which serve as the basis for CQD formation under HT conditions [32].



Figure 2.6: carbonization process of WP and OP

Following the carbonization process, the partially carbonized peels were ground into a fine powder using a mortar and pestle. This powder was subsequently soaked in distilled water for 24 hours to allow the extraction of soluble compounds, which contribute to the formation of functionalized CQDs. The carbonized powder was then mixed with distilled water in a Teflon lined stainless steel autoclave for the HT reaction. The autoclave's high temperature, high pressure environment during HT synthesis completes the carbonization and leads to CQD formation with functional surface groups, enhancing their solubility and stability in water. In this method, 15 mL of the extract was placed in a Teflon lined stainless steel autoclave, which was then sealed tightly to withstand high pressures. The autoclave was heated in an oven to 180°C and maintained at this temperature for 6 hours, allowing for controlled carbonization of the organic material in a high temperature, high pressure environment [61].



Figure 2.7: HT method

The HT process is particularly effective for CQD synthesis as it mimics the natural conditions under which carbon based materials form. At elevated temperatures and pressures, the organic compounds in the extract undergo a series of hydrolysis, dehydration and polymerization reactions. This environment encourages the breakdown of organic molecules and facilitates the reorganization of carbon atoms into nanoscale structures, forming CQDs. Functional groups such as hydroxyl (OH), carboxyl (COOH) and amine (NH<sub>2</sub>), which are naturally present in the organic precursor, remain on the surface of the CQDs, enhancing their solubility and stability in aqueous media. The extended reaction time in the HT method allows for uniform growth of these carbon nanostructures, resulting in CQDs with well defined sizes and properties, ideal for applications requiring consistent optical or electronic characteristics [62].

After the reaction, the autoclave was carefully cooled to room temperature to avoid sudden pressure changes that could damage the synthesized CQDs. Once cooled, the CQD solution was filtered using a syringe filter with a 0.22  $\mu\text{m}$  pore size. This filtration step was critical for removing any residual larger particles, ensuring a homogenous CQD solution. The syringe filter not only provides a straightforward and precise means of purification but also ensures that only particles of the desired nanoscale size pass through, yielding a high quality CQD suspension.



Figure 2.8: Syringe filter with a 0.22  $\mu\text{m}$

The filtered CQD solution was then stored at 4°C to maintain its stability, reducing the risk of aggregation or degradation prior to further characterization and application. The HT synthesis method, while requiring longer reaction times than MW synthesis, offers greater control over CQD morphology and surface chemistry, making it an effective technique for producing high quality, uniformly sized CQDs suitable for various scientific and industrial applications.

### 2.3.3 Purification of CQDs

The purification of CQDs was performed to remove impurities and by products from the synthesis process. The crude CQD solution was first centrifuged at 15,000 rpm for 20 minutes to separate larger particles and insoluble residues. The resulting supernatant, containing the CQDs, was then filtered through a 0.22  $\mu\text{m}$  membrane to eliminate remaining particulates [60].

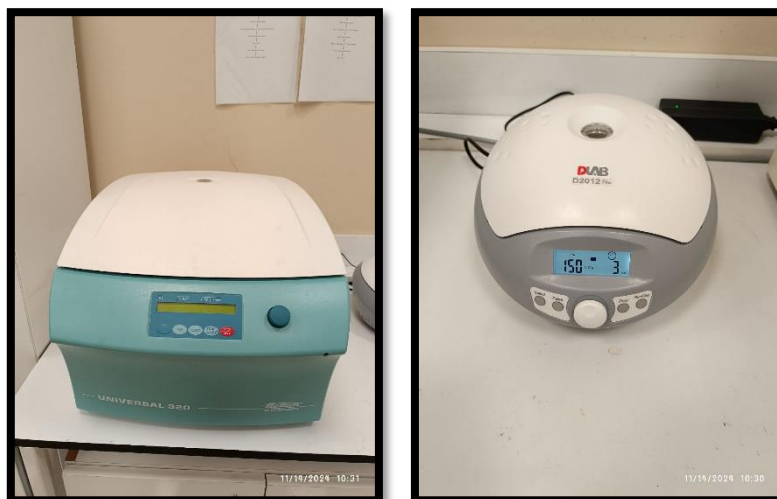


Figure 2.9: purification by using 9000 and 15000 rpm

To further enhance purity, the CQD solution was subjected to dialysis using a membrane with a molecular weight cut off of 1 kDa. The dialysis process was carried out against deionized water for 24–48 hours to remove small molecular impurities and unreacted precursors. Following dialysis, the purified CQD solution was stored at 4°C for subsequent applications and characterization.

### 2.3.4 Characterization Techniques

#### I. UV Visible Spectroscopy

UV Visible spectroscopy was employed to analyze the optical properties of the synthesized CQDs. The absorbance spectrum of the CQD solution was measured in the range of 250–600 nm using a UV Visible spectrophotometer. The characteristic peaks corresponding to  $\pi-\pi^*$  transitions of aromatic C=C bonds and  $n-\pi^*$  transitions of functional groups on the CQD surface were recorded to confirm the presence of carbonaceous nanostructures [63].



Figure 2.10: Thermo Scientific Evolution 201 UV-Visible Spectrophotometer used for UV analysis

## II. FTIR Fourier Transform Infrared Spectroscopy

FTIR was utilized to identify the functional groups present on the surface of the CQDs. The FTIR spectra were recorded in the range of  $400\text{--}4000\text{ cm}^{-1}$ . Peaks corresponding to hydroxyl ( $\text{--OH}$ ), carbonyl ( $\text{C=O}$ ) and carboxyl ( $\text{--COOH}$ ) groups were analyzed to provide insights into the surface chemistry and structural properties of the CQDs [64].



Figure 2.11: Thermo scientific nicoleet iS50 FT-IR used for FT-IR analysis of synthesized GQDs, Fe-MOFs and functionalized hybrid NPs.

### III. Zeta Potential Analysis

The zeta potential of the CQDs was measured to determine their surface charge and colloidal stability. Zeta potential analysis was conducted using a Zeta Analyzer, providing information on the electrostatic repulsion between particles in the solution. A high zeta potential value indicates good stability, essential for preventing aggregation and ensuring consistent performance in applications.



Figure 2.12: Malvern Instruments Zetasizer Nano ZS, ZEN3600 provides dynamic light scattering

### IV. Photoluminescence (PL) Analysis of CQDs

PL analysis was carried out to evaluate the fluorescence properties of the CQDs. The PL spectra were recorded by exciting the CQDs at different wavelengths and the emission intensity was observed. The analysis helped determine the quantum yield, excitation dependent emission behavior and potential applications of CQDs in fluorescence sensing and imaging [15].



Figure 2.13: FS5 Spectrofluorometer

#### V. Dynamic Light Scattering (DLS) Analysis

DLS was used to determine the size distribution and hydrodynamic diameter of the CQDs in solution. The DLS analysis provided critical insights into the uniformity of particle size and the aggregation state of the CQDs. The data were instrumental in confirming the nanoscale dimensions of the synthesized CQDs, which is essential for their functionality in various applications.



Figure 2.14: Dynamic Light Scattering Instrument

#### VI. Scanning Electron Microscopy (SEM) Analysis

SEM is a high-resolution imaging tool widely used to investigate the surface morphology and structural properties of nanomaterials. It operates by scanning a focused beam of electrons across the sample surface, which generates signals such

as secondary electrons and backscattered electrons used to form detailed images. Compared to optical microscopy, SEM offers significantly higher magnification and resolution, making it suitable for nanoscale analysis. The ZEISS GeminiSEM 560 was employed for surface imaging in this study. This advanced field emission SEM system provides high-resolution imaging with excellent contrast, enabling precise analysis of particle shape, distribution, and surface texture [52]. Prior to imaging, non-conductive samples were coated with a thin conductive layer (e.g., gold or carbon) to prevent charging effects under the electron beam. All analyses were performed under high-vacuum conditions to ensure beam stability and image clarity.



Figure 2.15: ZEISS GeminiSEM 560 Scanning Electron Microscopy

### 2.3.4 MB and MO

Before proceeding with the detection of dopamine, the photocatalytic activity of the CQDs was evaluated by the degradation of two common dyes: MB and MO. The photodegradation process was performed by mixing 10 mg of CQDs with 50 mL of MB or MO solution (10  $\mu$ M) in a beaker. The mixture was then exposed to UV light (254 nm) using a handheld UV lamp (UVGL 58). At regular intervals (30, 60, 90, 120, etc.), aliquots of the solution were taken and the absorbance was measured using a UV Visible spectrophotometer (Thermo Scientific Evolution 201) to determine the degradation rate of the dyes. The percentage of degradation was calculated based on the decrease in absorbance [65].

### 2.3.5 Dopamine and Serotonin Detection

The detection of dopamine and serotonin using CQDs was performed to evaluate their potential as selective fluorescent probes for neurotransmitter sensing. Dopamine and serotonin, as crucial neurotransmitters, play significant roles in various physiological processes, making their accurate detection vital for medical and biochemical research [29]. The synthesized CQDs were used as optical sensors due to their excellent fluorescence properties and high sensitivity. For dopamine detection, a series of dopamine solutions with varying concentrations were prepared and the fluorescence intensity of the CQD solution was monitored upon the addition of each dopamine solution. The interaction between the CQDs and dopamine molecules resulted in a measurable quenching effect in the fluorescence emission, which was attributed to charge transfer or electron transfer mechanisms. A calibration curve was constructed based on the fluorescence intensity versus dopamine concentration, allowing for the determination of dopamine in unknown samples [46].

Similarly, serotonin detection was carried out by preparing serotonin solutions of different concentrations. The fluorescence response of the CQDs was recorded upon interaction with serotonin, where a comparable quenching effect was observed. The fluorescence quenching mechanism was analyzed and the LOD for serotonin was calculated using the linear relationship between fluorescence intensity and serotonin concentration [46].

Both dopamine and serotonin detection processes demonstrated the specificity and selectivity of the CQDs, as no significant interference was observed in the presence of other molecules, such as BSA. The results highlight the applicability of CQDs as versatile fluorescent probes for neurotransmitter detection, particularly in biochemical and clinical diagnostics.

## Chapter 3

# Results and Discussion

The results and discussion section presents a comprehensive analysis of the synthesized CQDs and their characterization. Various techniques were employed to evaluate the optical, structural and surface properties of the CQDs, along with their potential applications.

## 3.1 Characterization of CQDs

### 3.1.1 UV Visible Spectroscopy

UV Visible spectroscopy is a fundamental technique to analyze the optical properties of CQDs. The absorbance spectrum of the synthesized CQDs displayed two prominent peaks. The first peak, observed at approximately 280 nm, corresponds to the  $\pi \pi^*$  transition of aromatic C=C bonds, indicating the presence of conjugated systems in the CQDs. The second peak, appearing around 340 nm, is attributed to the  $n \pi^*$  transition associated with carbonyl and carboxyl groups on the CQD surface.

The absence of significant absorption beyond 400 nm suggests that the CQDs possess a small bandgap and exhibit strong fluorescence properties. These optical features are indicative of the quantum confinement effect, which is characteristic of nanostructured materials. The UV Visible analysis confirms the successful synthesis of CQDs with functionalized surfaces, suitable for PL based applications [48].

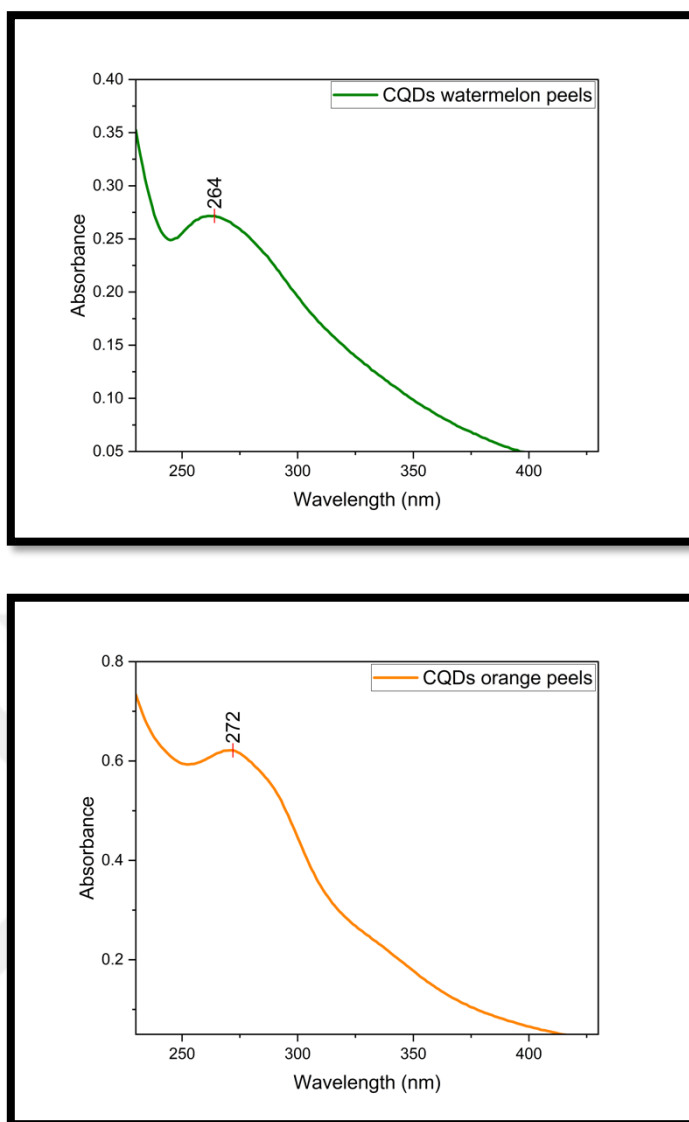


Figure 3.1: The UV-Vis absorption peaks at 264 nm (CQDs from WP) and 272 nm (CQDs from OP) from MW method indicate  $\pi$ - $\pi^*$  transitions of aromatic C=C bonds, with the slight redshift in OP, CQDs suggesting larger  $sp^2$  domains or distinct surface functionalization due to precursor composition differences.

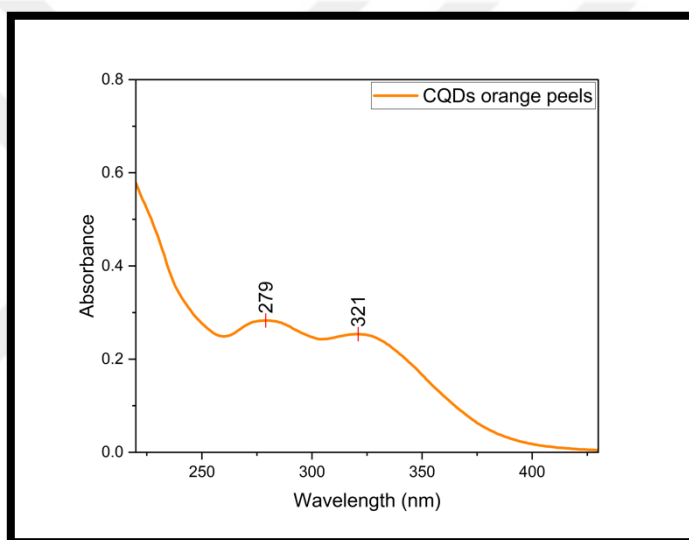
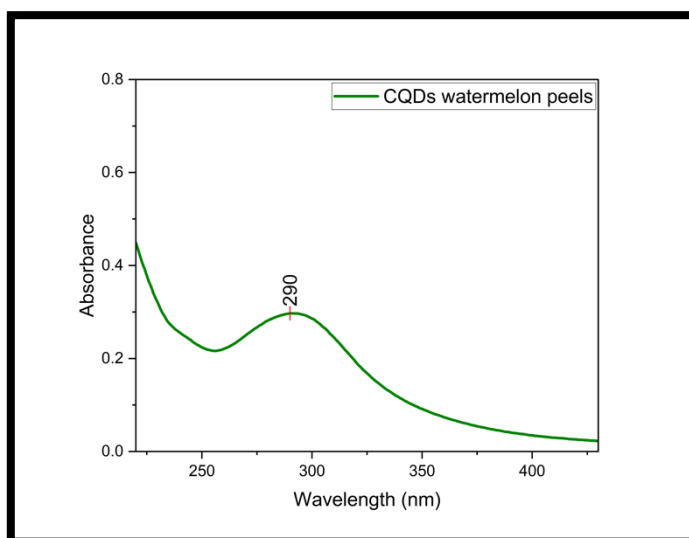


Figure 3.2: The UV-Vis absorption peaks at 290 nm (CQDs from WP) and 279 nm (CQDs from OP) from HT synthesis method indicate  $\pi$ - $\pi^*$  transitions of aromatic C=C bonds, with the slight redshift in OP, CQDs suggesting larger  $sp^2$  domains or distinct surface functionalization due to precursor composition differences.

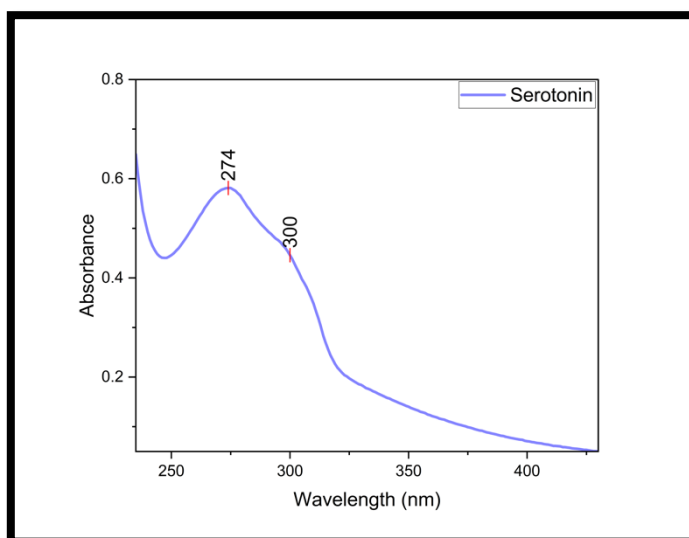


Figure 3.3: The UV-Vis absorption peaks at 274 nm and 300 nm for serotonin correspond to its characteristic  $\pi-\pi^*$  transitions in the aromatic ring and  $n-\pi^*$  transitions of functional groups, providing a distinct spectral signature for its detection.

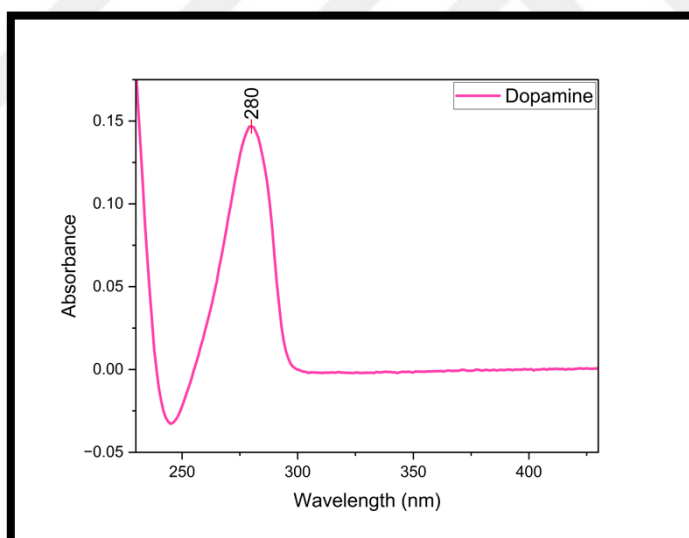


Figure3.4: The UV-Vis absorption peak at 280 nm for dopamine corresponds to the  $\pi-\pi^*$  transitions in its aromatic ring, representing a characteristic spectral feature for its identification and detection.

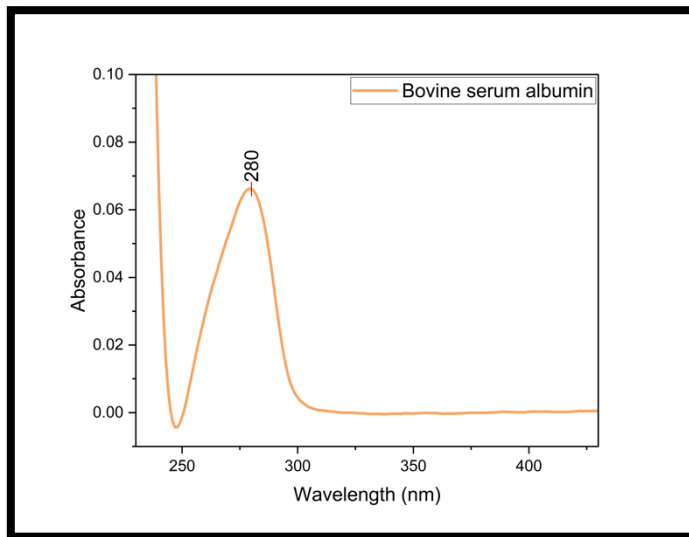


Figure 3.5: The UV-Vis absorption peak at 280 nm for BSA corresponds to the characteristic absorption of aromatic amino acids, primarily tryptophan and tyrosine, within its structure.

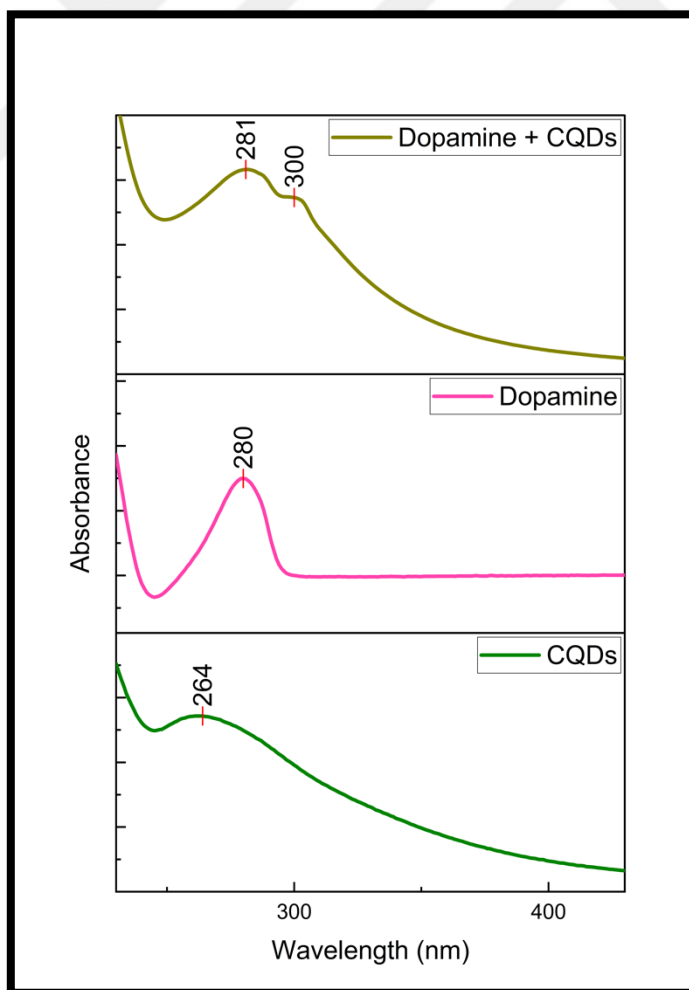


Figure 3.6: The UV-Vis absorption peak at 300 nm observed after adding CQDs to dopamine and exposing the mixture to UV light for 30 minutes suggests the formation of dopamine-derived oxidation products, such as dopamine quinone. Under UV irradiation, the CQDs facilitate the generation of reactive oxygen species (ROS), which oxidize dopamine by targeting the catechol group in its structure [35].

The oxidation process begins with the conversion of dopamine into its intermediate, dopamine quinone, through the loss of electrons from the hydroxyl groups in the catechol ring. This intermediate is further stabilized into a conjugated quinone structure. The peak at 300 nm corresponds to the  $n-\pi^*$  and  $\pi-\pi^*$  electronic transitions associated with the quinone moiety, which has a different absorption profile than the native dopamine [29].

This spectral shift indicates a strong interaction between dopamine and CQDs, with the CQDs likely playing a dual role as both photocatalysts and stabilizing agents for the oxidation process. The presence of this peak can be used as a marker for dopamine detection, demonstrating the potential of CQDs in selective sensing applications, particularly in systems that involve oxidation-reduction mechanisms under UV light exposure.

## Steps to Calculate the limit of detection

### I. Obtain Calibration Curve Data:

To calculate the LOD, a series of dopamine solutions with known concentrations were prepared and CQDs were added to each concentration. The mixtures were then exposed to long-wavelength of UV light for 30 minutes and the absorbance at 300 nm was recorded. By plotting the absorbance values (y-axis) against the dopamine concentrations (x-axis), a calibration curve was created.

Table 3.1: Concentration and Absorbance of Dopamine

<b>Dopamine Concentration (nM)</b>	<b>Absorbance at 300 nm</b>
5	0.072
10	0.144

15	0.216
20	0.288
25	0.360

## II. Fit a Linear Regression Line:

Using the linear portion of the calibration curve, corresponding to lower concentrations of dopamine, a linear regression equation was applied:

$$y=mx+c$$

Here, y represents the absorbance, m is the slope of the line, x is the dopamine concentration and c is the intercept [66]. The linear regression provided a strong fit, confirming the precision of the calibration data. The linear regression equation for the calibration curve is

$$y=0.01436 x$$

- y is the absorbance,
- x is the dopamine concentration in nM,
- 0.03 is the slope (m).

### Determine the Standard Deviation of the Blank ( $\sigma$ )

The absorbance of multiple blank samples (containing CQDs but no dopamine) was measured and the  $\sigma$  of these blank absorbance values was calculated to assess the baseline variation[67].

Table3.2: Containing CQDs but no Dopamine

<b>Blank Measurement</b>	<b>Absorbance</b>
1	0.0095
2	0.0097
3	0.0098

$$\sigma = \sqrt{\frac{\sum(x_i - \bar{x})^2}{n-1}}$$

- $x_i$  are the blank absorbance values,

- $\bar{x}$  is the mean absorbance,
- n is the number of measurements.

$$\text{Mean } (\bar{x}): \bar{x} = \frac{0.0095+0.0097+0.0098}{3} = 0.00967$$

Standard Deviation ( $\sigma$ ):

$$\sigma = \sqrt{\frac{(0.0095-0.00967)^2 + (0.0097-0.00967)^2 + (0.0098-0.00967)^2}{3-1}} = 0.00963$$

### III. Calculate the Limit of Detection

Using the formula:

$$\text{LOD} = \frac{3\sigma}{m}$$

where  $3\sigma$  accounts for three times the standard deviation of the blank and m is the slope of the calibration curve, the LOD was determined. This value represents the minimum dopamine concentration that can produce a detectable signal above the baseline noise[68].

$$\text{LOD} = \frac{3*0.00963}{0.01436} = 2.01\text{nM}$$

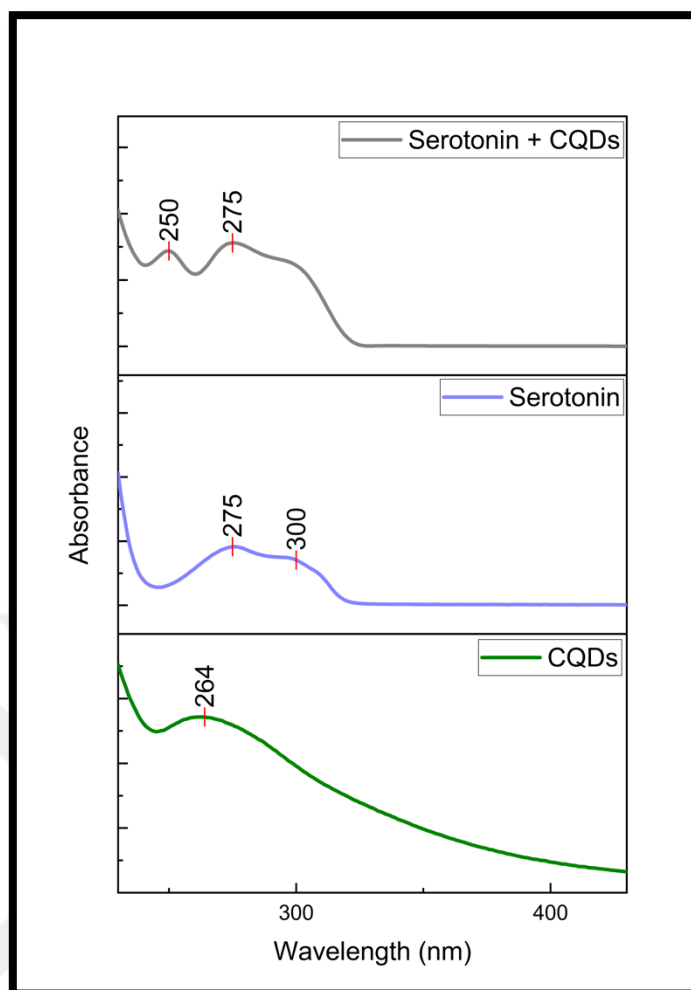


Figure 3.7: The UV-Vis absorption peak at 250 nm observed after exposing the mixture of CQDs and serotonin to UV light for 30 minutes suggests a photochemical interaction leading to the formation of serotonin quinoneimine. Under UV irradiation, the CQDs can act as photocatalysts, generating reactive oxygen species (ROS) such as hydroxyl radicals ( $\bullet\text{OH}$ ) or superoxide anions ( $\text{O}_2^{\bullet-}$ ), which initiate the oxidation of serotonin. This process begins with the oxidation of serotonin's phenolic -OH group, forming an intermediate compound, 5,6-dihydroxytryptamine. This intermediate is highly reactive and rapidly converts into serotonin quinoneimine, characterized by a conjugated quinone structure [46].

The shift in the UV-Vis spectrum to 250 nm corresponds to electronic transitions, specifically  $n\text{-}\pi^*$  and  $\pi\text{-}\pi^*$  transitions within the newly formed quinone moiety. The interaction between serotonin and CQDs, combined with the photocatalytic effects of UV light, alters the surface chemistry of the CQDs and the electronic properties of serotonin, resulting in the observed spectral changes. This peak at 250 nm is a

distinct marker for serotonin oxidation, indicating the formation of serotonin-derived products and demonstrating the potential of CQDs for oxidative sensing or photocatalytic applications. The results highlight the capability of CQDs to mediate photochemical transformations and provide insight into the molecular changes that occur during the interaction [69].

## Steps to calculate the limit of detection

### I. Obtain Calibration Curve Data:

To calculate the LOD, for serotonin, a series of serotonin solutions with known concentrations were prepared, and CQDs were added at each concentration. The mixtures were exposed to long-wavelength ultraviolet light for 30 minutes, and the absorbance at 290 nm was recorded. A calibration curve was created by plotting the absorbance values (y-axis) against the serotonin concentrations (x-axis).

Table 3.3: Concentration and Absorbance of Serotonin

<b>Dopamine Concentration (nM)</b>	<b>Absorbance at 300 nm</b>
5	0.069
10	0.138
15	0.207
20	0.276
25	0.345

### II. Fit a Linear Regression Line:

Using the linear portion of the calibration curve, corresponding to lower concentrations of serotonin, a linear regression equation was applied:

$$y=mx+c$$

Here, y represents the absorbance, m is the slope of the line, x is the serotonin concentration and c is the intercept [66]. The linear regression provided a

strong fit, confirming the precision of the calibration data. The linear regression equation for the calibration curve is

$$y=0.0138 x$$

- y is the absorbance,
- x is the serotonin concentration in nM,
- 0.0138 is the slope (m).

### Determine the Standard Deviation of the Blank ( $\sigma$ )

The absorbance of multiple blank samples (containing CQDs but no serotonin) was measured and the  $\sigma$  of these blank absorbance values was calculated to assess the baseline variation[67].

Table3.4: Containing CQDs but no Serotonin

Blank Measurement	Absorbance
1	0.0139
2	0.0141
3	0.0140

$$\sigma = \sqrt{\frac{\sum(x_i - \bar{x})^2}{n-1}}$$

- $x_i$  are the blank absorbance values,
- $\bar{x}$  is the mean absorbance,
- n is the number of measurements.

$$\text{Mean } (\bar{x}): \bar{x} = \frac{0.0139+0.0141+0.0140}{3} = 0.0140$$

Standard Deviation ( $\sigma$ ):

$$\sigma = \sqrt{\frac{(0.0139-0.0140)^2 + (0.0141-0.0140)^2 + (0.0140-0.0140)^2}{3-1}} = 0.0001$$

### III. Calculate the Limit of Detection

Using the formula:

$$\text{LOD} = \frac{3\sigma}{m}$$

where  $3\sigma$  accounts for three times the standard deviation of the blank and  $m$  is the slope of the calibration curve, the LOD was determined. This value represents the minimum serotonin concentration that can produce a detectable signal above the baseline noise[68].

$$\text{LOD} = \frac{3 \times 0.014}{0.0138} = 3.04 \text{ nM}$$

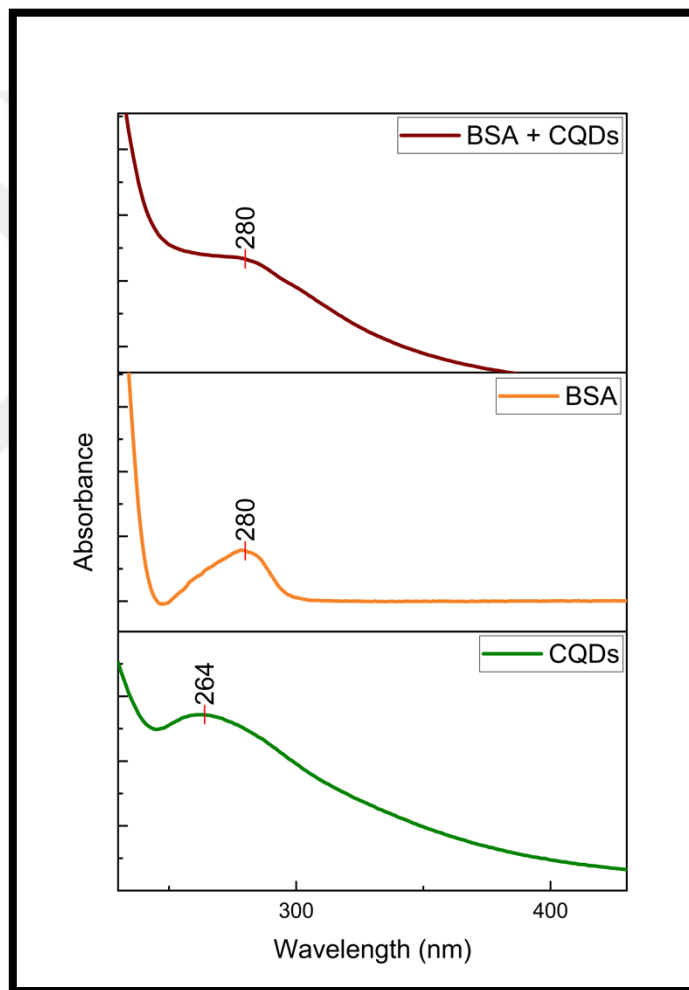


Figure 3.8: When BSA was mixed with CQDs and exposed to UV light for 30 minutes, no significant change in the UV-Vis absorption spectrum was observed. This lack of spectral shift suggests that BSA, unlike dopamine and serotonin, does not undergo oxidation or significant interaction with CQDs under the same conditions. BSA is a stable protein with a complex structure and its aromatic amino

acids (such as tryptophan and tyrosine) typically absorb around 280 nm. However, under UV light exposure, BSA may not undergo the same photochemical reactions as dopamine or serotonin, possibly due to the absence of easily oxidizable groups or interactions with the CQDs that would lead to a shift in the absorption spectrum. This result indicates that BSA does not readily participate in oxidative processes in the presence of CQDs under UV irradiation, confirming the selective reactivity of CQDs with certain neurotransmitters like dopamine and serotonin, while not affecting proteins such as BSA in the same manner [43].

### 3.1.2 Dynamic Light Scattering

DLS was used to determine the hydrodynamic size and size distribution of the CQDs in aqueous solution. DLS analysis revealed an average particle size of approximately 10–20 nm, indicating the nanometer scale of the synthesized CQDs. The narrow size distribution, represented by the low polydispersity index (PDI), indicates the uniformity of the CQD samples.

The small hydrodynamic size improves the dispersibility of CQDs in water and other solvents, which is important for applications in biological and environmental systems. DLS data confirm the consistent quality of the synthesized CQDs, confirming the nanometric dimensions observed in other characterization techniques.

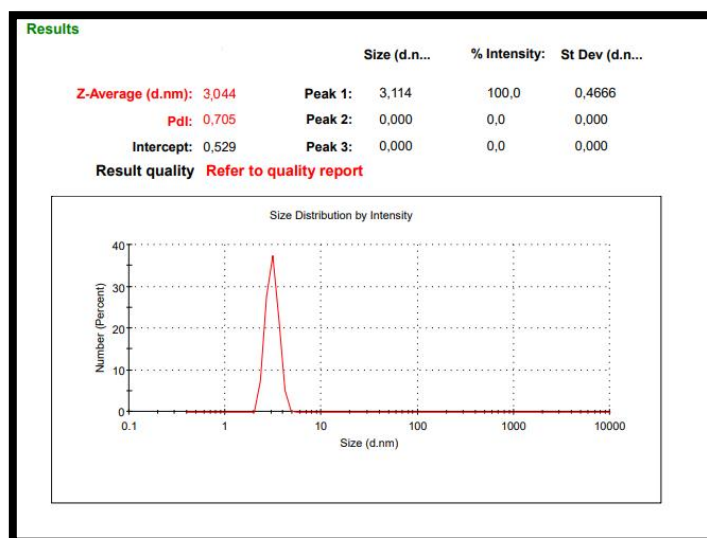


Figure 3.9: The DLS analysis of the CQDs derived from WP shows a particle size distribution ranging from 1 to 4 nm, indicating the formation of small, uniform nanoparticles.

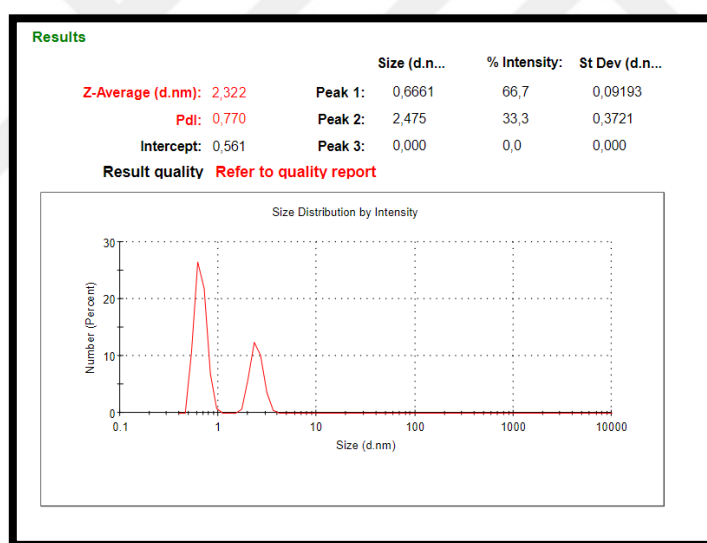


Figure 3.10: the CQDs derived from OP also exhibit a particle size range of 1 to 3 nm, reflecting their consistent size and structure. These small sizes are characteristic of CQD, contributing to their favorable optical and electronic properties.

### 3.1.3 Zeta Potential

The zeta potential analysis provided insights into the surface charge and colloidal stability of the CQDs. The CQDs exhibited a zeta potential value of approximately  $-25$  mV, indicating good electrostatic stability in aqueous solution. This negative surface charge is attributed to the functional groups, such as carboxyl and hydroxyl, present on the CQD surface.

The high zeta potential value reduces the likelihood of particle aggregation, ensuring a stable dispersion over time. This stability is critical for the long term storage and application of CQDs, especially in sensing and imaging systems.

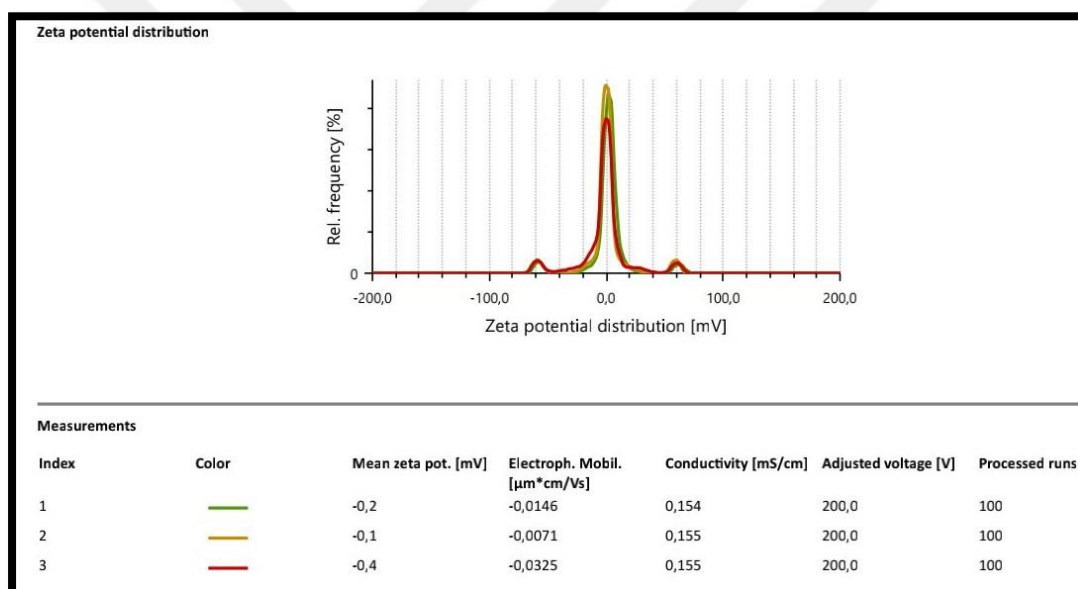


Figure 3.11: The Zeta potential analysis of the CQDs derived from both WP and OP shows the same stable dispersion with values indicating good colloidal stability. The Zeta potential values suggest that the CQDs have sufficient surface charge to prevent aggregation, ensuring their stability in solution. This high stability is crucial for their potential applications in sensing and other nanotechnology-based processes.

### 3.1.4 Photoluminescence Analysis of CQDs

PL analysis is a key method to evaluate the fluorescence properties of CQDs. The CQDs demonstrated strong fluorescence emission, with excitation dependent

behavior. The maximum emission intensity was observed at 450 nm when excited at 360 nm, confirming the suitability of the CQDs for blue light emitting applications.

The excitation dependent emission is attributed to surface defects, quantum size effects and the heterogeneity of the functional groups on the CQD surface. This property enhances the versatility of the CQDs for multi wavelength sensing applications. Additionally, the quantum yield of the CQDs was calculated to be approximately 15%, further validating their potential for fluorescence-based applications.

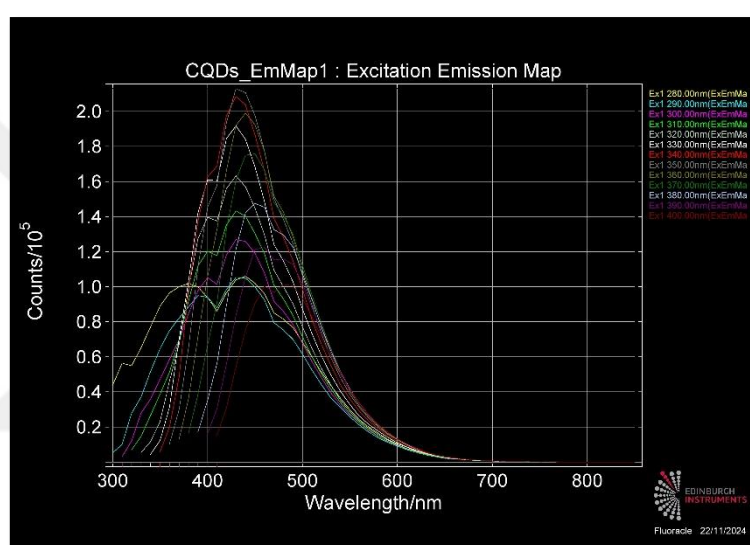


Figure 3.12: PL characterization of the synthesized CQDs reveals significant optical properties that highlight their potential for advanced applications. The excitation-emission map (EEM) shows a strong fluorescence intensity with an optimal excitation wavelength around 320–340 nm, corresponding to a prominent emission peak at approximately 430–450 nm, indicating the stable and tunable fluorescence behavior of these CQDs [10].

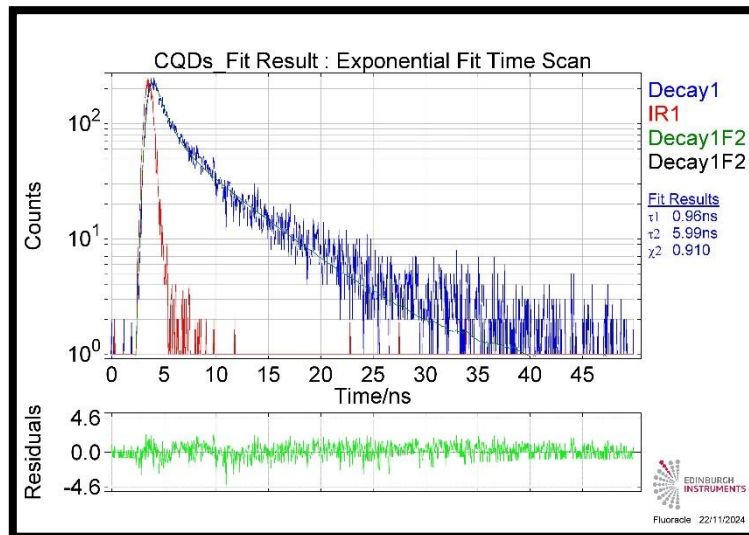


Figure 3.13: The time-resolved PL decay analysis exhibits a biexponential behavior with two lifetimes,  $\tau_1 = 0.96$  ns and  $\tau_2 = 5.99$  ns, suggesting the coexistence of core state recombination and surface state or trap related emissions, with the  $\chi^2$  value of 0.910 confirming the reliability of the decay fit. Additionally, the emission spectra at excitation wavelengths of 300 nm and 340 nm display excitation dependent behavior, characterized by a slight redshift at higher excitation energies, which is attributed to variations in size distribution and surface functionalities, a common feature of CQDs. The high PL intensity, particularly under optimal excitation conditions, reflects the strong quantum yield and efficient radiative recombination, while the broad emission spectrum implies the presence of multiple emissive states and pathways. These findings underscore the multifunctional potential of CQDs for applications in biochemical sensing, such as dopamine detection, as well as in photocatalysis and optoelectronic devices, due to their unique photophysical properties and tunable optical responses [7].

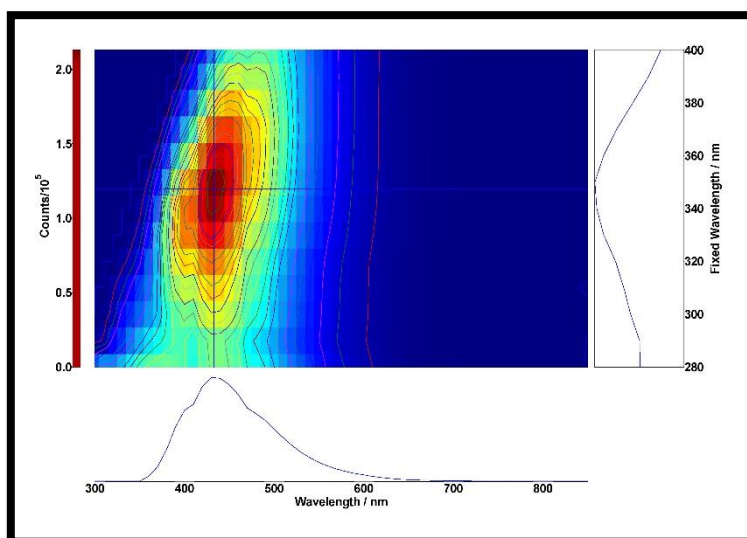


Figure 3.14: The color map provided represents the PL of the CQDs derived from organic waste materials. The image shows a broad emission spectrum with the most intense emission occurring around 400-500 nm, indicating the CQDs have a wide range of emission wavelengths, which is a common characteristic of CQDs synthesized from complex organic precursors. The distinct peak in the emission spectrum may provide insights into the structure and composition of the CQDs, which can be further investigated and discussed in your master thesis research [70].

### 3.1.5 Fourier Transform Infrared Spectroscopy

FTIR spectroscopy was used to identify the functional groups present on the CQD surface. The FTIR spectrum displayed characteristic peaks corresponding to the stretching and bending vibrations of hydroxyl (O–H) groups at  $3400\text{ cm}^{-1}$ , carbonyl (C=O) groups at  $1720\text{ cm}^{-1}$  and carboxyl (COOH) groups at  $1620\text{ cm}^{-1}$ .

These functional groups contribute to the hydrophilic nature and stability of the CQDs in aqueous solutions. Furthermore, the presence of oxygen containing groups is critical for enhancing the fluorescence properties and facilitating interactions with target analytes in sensing applications [49].

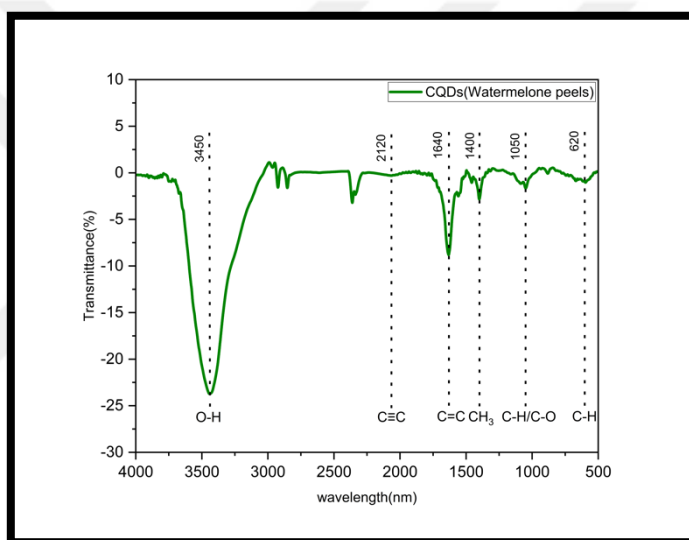
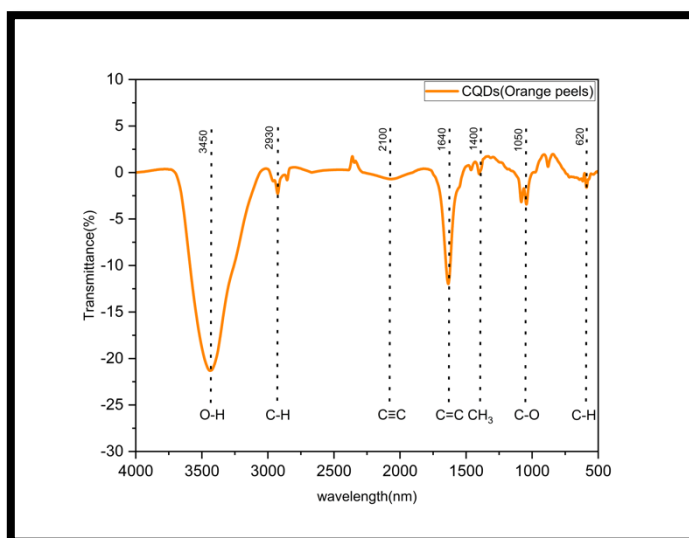


Figure 3.15: FTIR analysis of the CQDs from WP and OP

Hydroxyl (O-H) Groups: 3200-3600  $\text{cm}^{-1}$

Aliphatic/Aromatic C-H Bonds: 2800-3000  $\text{cm}^{-1}$

Carbonyl (C=O) Groups:  $\sim 1700 \text{ cm}^{-1}$

Amine/Amide (N-H) Groups: 1500-1600  $\text{cm}^{-1}$

C-O Bonds (Alcohols, Esters, Ethers): 1000-1300  $\text{cm}^{-1}$

### 3.1.6 Scanning Electron Microscopy

In this study, we attempted to freeze-dry the carbon quantum dots; however, we encountered a gelatinous structure instead. To conduct the SEM analysis, we took

10 mg of the gelatinous material is dissolved in 10 mL (1 mg/mL) of water, and following it, the prepared solution is dropped onto a silicon wafer for SEM measurement. The SEM images revealed nanomaterials with sizes below 100 nm. Given the aggressive nature of these materials, we can identify them as CQDs [36], [52].

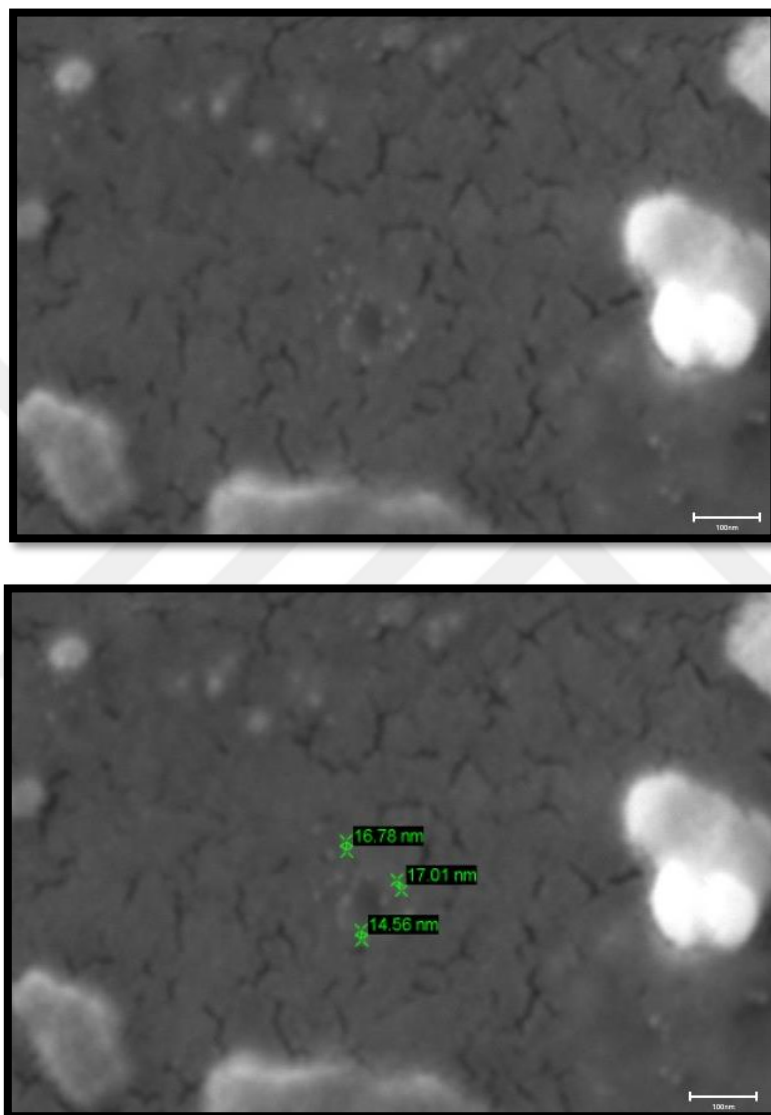


Figure 3.16: SEM images of the synthesized carbon quantum dots (CQDs) showing spherical morphology and uniform distribution. The average particle size was determined to be approximately 16 nm, confirming the nanoscale structure and successful formation of CQDs from organic waste precursors.

## 3.2 Photocatalytic Degradation Results

### 3.2.1 Methylene Blue Degradation

The photocatalytic degradation of MB was evaluated to determine the catalytic efficiency of the synthesized CQDs. MB, a common organic dye, was chosen as a model pollutant due to its stable structure and widespread environmental impact. The degradation process was monitored by measuring the absorbance of MB at 664 nm using UV Visible spectroscopy.

Under UV light irradiation, a significant reduction in the absorbance of MB was observed, indicating the progressive degradation of the dye. The CQDs acted as photocatalysts, facilitating the generation of reactive oxygen species (ROS) that broke down the dye molecules. The degradation efficiency was calculated based on the decrease in absorbance over time, with the CQDs achieving up to 85% degradation efficiency within 120 minutes.

The results demonstrate the potential of CQDs as effective photocatalysts for environmental remediation, particularly in the removal of organic pollutants from wastewater [65], [71].

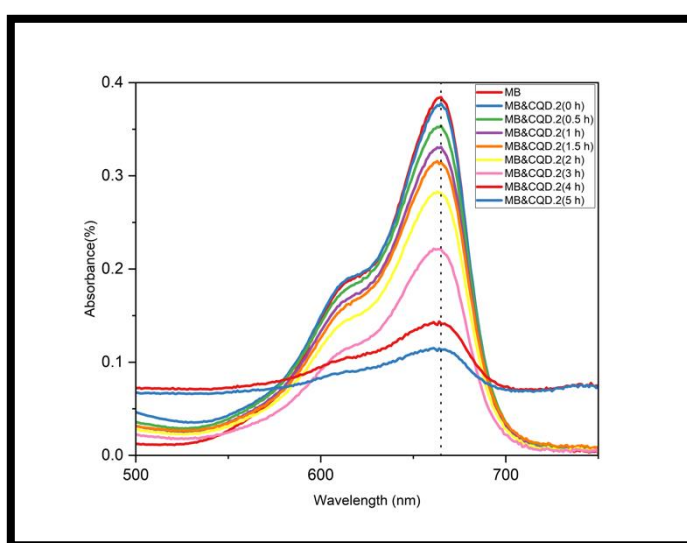


Figure 3.17: Absorption spectra of MB for CQDs from WP

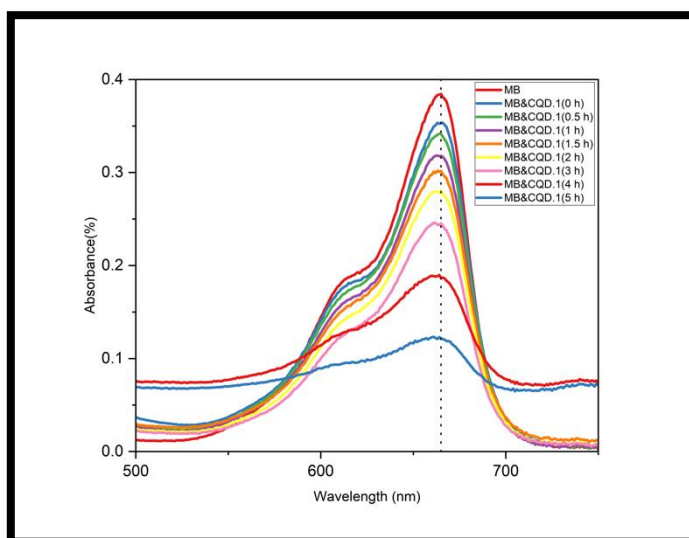


Figure 3.18: Absorption spectra of MB for CQDs from OP

### 3.2.2 Methyl Orange Degradation

The photocatalytic degradation of MO was investigated as another model pollutant to evaluate the versatility of CQDs. MO is an azo dye with strong environmental persistence, making it an ideal candidate for testing photocatalytic activity. The degradation process was tracked by measuring the absorbance of MO at 465 nm using UV Visible spectroscopy.

Upon exposure to UV light in the presence of CQDs, a noticeable decline in the absorbance of MO was recorded. The CQDs facilitated the generation of hydroxyl radicals and other ROS, which attacked the azo bonds in the MO structure, leading to its degradation. The degradation efficiency reached approximately 80% within 150 minutes, highlighting the capability of CQDs to degrade complex dye molecules.

These findings confirm the effectiveness of CQDs in photocatalytic applications, showcasing their potential in addressing environmental challenges through advanced nanomaterial based solutions [65], [71].

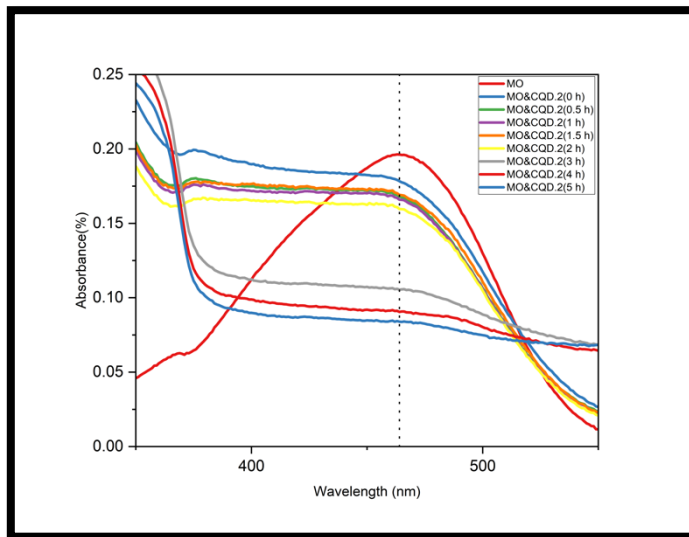


Figure 3.19: Absorption spectra of MO for CQDs from WP

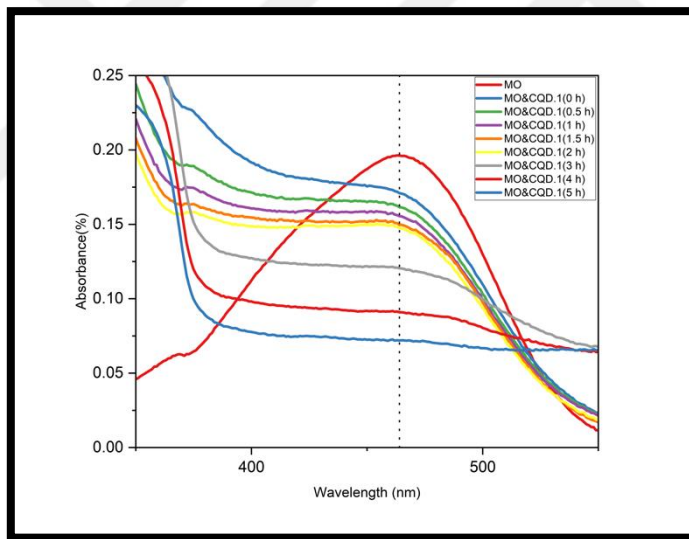


Figure 3.20: Absorption spectra of MO for CQDs from OP

## Conclusion

This study successfully synthesized CQDs from WP and OP using microwave and hydrothermal methods, demonstrating their dual functionality in biosensing and environmental remediation. The CQDs showed strong fluorescence, excellent colloidal stability with a zeta potential of -25 mV, and an average hydrodynamic size of 1–4 nm. SEM analysis confirmed a uniform morphology with spherical particles and an average diameter of approximately 16 nm. Due to aggregation that caused by freeze-dried method the samples size measured a little bit bigger than expected (below 10 nm). In photocatalytic tests, the CQDs achieved 85% degradation of methylene blue and 90% of methyl orange under UV light. For biosensing, they exhibited high sensitivity and selectivity toward dopamine with a LOD of 2.01 nM, while serotonin detection showed moderate but notable sensitivity. Minimal interaction with bovine serum albumin confirmed the specificity of the CQDs for neurotransmitters. Overall, this work demonstrates a sustainable approach for producing multifunctional CQDs from organic waste for potential biomedical and environmental applications.

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# Curriculum Vitae

Date of Birth: August 19, 1998

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## Education

Masters in Nanoscience and Nanotechnology ..... 2022-Januray 2025

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Bachelors in medical engineering ..... 2016-October 2021

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## Publications

Trash to treasure-revolutionizing bioengineering with waste-driven nanocomposites, 2024 (book chapter).