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ABSTRACT

Orange waste peel CQDs has been synthesized via simple hydrothermal method. The UV–visible spectrum shows near band edge absorbance and optical energy bandgap has been calculated as 3.44 eV and 5.60 eV. In addition, the antibacterial assay of CQDs was carried out against two kind of bacteria such as gram positive and gram-negative bacteria. It has been noted that the CQDs show good antibacterial activity towards the gram-negative bacterium *Pseudomonas aeruginosa* (ZOI: 30 mm). Antibacterial activity of natural waste CQDs was compared with chemically synthesized NPs and QDs.

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1. Introduction

In recent years, the study of fabrication of one-dimension (1D) nanostructures like quantum dots has been attracted tremendous attention due to their intriguing attentions [1–3]. However, among these nanoscale materials have expected to many potential future applications both in microscopic research and development of mechanisms [4,5]. Specifically, carbon based one-dimension nanostructures possess good characteristics pertaining to their optical and electronic properties induced by quantum confinement effect which enhances can emit tunable light depending upon size has much application in both optoelectronic and biological fields [6,7]. Interestingly, carbon quantum dots (CQDs) are commonly used in wide range of bio-applications like bio-imaging and sensing technologies, drug and gene delivery [8–10]. CQDs serve as reactive sites on the surface functional groups like hydroxyl, carboxyl, epoxy, amino, amides etc., [11]. Among these uses, antibacterial assay assessment can lead to low-cost diagnosis and fast intervention with minimal side effects and biocompatibility. Recently green synthesis techniques for the development of CQDs from different natural assets such as tapioca, banana juice, kitchan waste, lemon peels, watermelon peel etc., are reported [12–15]. In this context, it would be more fascinating to use waste materials as precursors to synthesis CQDs, as it offers waste management in addition to CQDs production. Our research group recently reported synthesis of CQDs using orange waste peels as a carbon source via simple hydrothermal method and optical studies are examined [16]. Therefore, in the present study morphological and antibacterial activity was tested against gram positive (*Bacillus cereus, Staphylococcus aureus*) and gram negative *(Pseudomonas aeruginosa, Vibrio cholerae,* and *Escherichia coli)* bacterial strains.

2. Experimental procedure

2.1. Synthesis of CQDs

The carbon quantum dots (CQDs) were prepared via simple hydrothermal method and the experimental procedure was already reported [16]. The starting material 2 g orange waste peel

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(yielded carbon) and 2 g citric acid was dissolved in 30 ml of deionized water and ammonia solution was added drop wise into the solution in order to maintain at pH 7. Then the solution was transferred into a Teflon-lined stainless-steel autoclave at 200 °C for 6 h. The obtained, CQDs for further analysed to various characterizations.

2.2. Antibacterial assay

The antibacterial assay of as-prepared carbon quantum dots was done on *Bacillus cereus, Staphylococcus aureus, Pseudomonas aeruginosa, Vibrio cholerae,* and *Escherichia coli* by disc diffusion method. In this assay, the sterilized petri dish was inhibited at 120 °C for 30 mins. The synthesized CQDs have been dispersed in deionized water. Then, the solution was pipetted out on sterile dishes on the bacterial plates using sterile forceps. The culture petri dishes were incubated at 37 °C and diameter of the zone (mm) was measured after 18 hrs.

3. Results and discussion

3.1. Morphological analysis

SEM micrographs of orange peel CQDs is shown in Fig. 1(a) and (b). It is used to investigate the presence of agglomeration and dispersion quality of the particle. SEM micrographs of CQDS (Fig. 1a) reveal the smooth and continuous surface and heterogeneous phase of as prepared CQDs. The one-micron magnification SEM image is shown in Fig. 1(b), that provides the expected formation of CQDs. The prepared CQDs have uneven rough edges at the outer surface which influence the antibacterial activity. Recently we have reported the same sample with mean diameter of CQDs 2.9 ± 0.5 nm and confirm the carbon structure with large numbers of residues present in the form hydroxyl and carboxyl groups on the CQDs [16].

3.2. UV– vis absorption spectrum analysis

The UV–vis absorption spectrum of the CQDs is depicted in Fig. 2(a). The CQDs shows near band edge absorbance at 235 nm and 332 nm. The optical energy bandgap of the prepared CQDs was estimated using Tauc's equation (1) [17].

$$(\alpha h\upsilon) = A(h\upsilon - E_g)^n \tag{1}$$

Where h is the Planck's constant, hυ is the photon energy, α is the absorption coefficient, E_g is the energy bandgap, υ frequency of incident light, A is the constant, n = 1/2 and n = 2 allowed direct transition and allowed indirect transitions respectively [17]. The plot of $(\alpha h\upsilon)^2$ *versus* hυ is shown in Fig. 2 (b & c). The optical energy bandgap values were calculated as 3.44 eV and 5.60 eV. The absorption of synthesized CQDs in the UV region suggests that it may have applications in optoelectronic and photocatalysis [18].

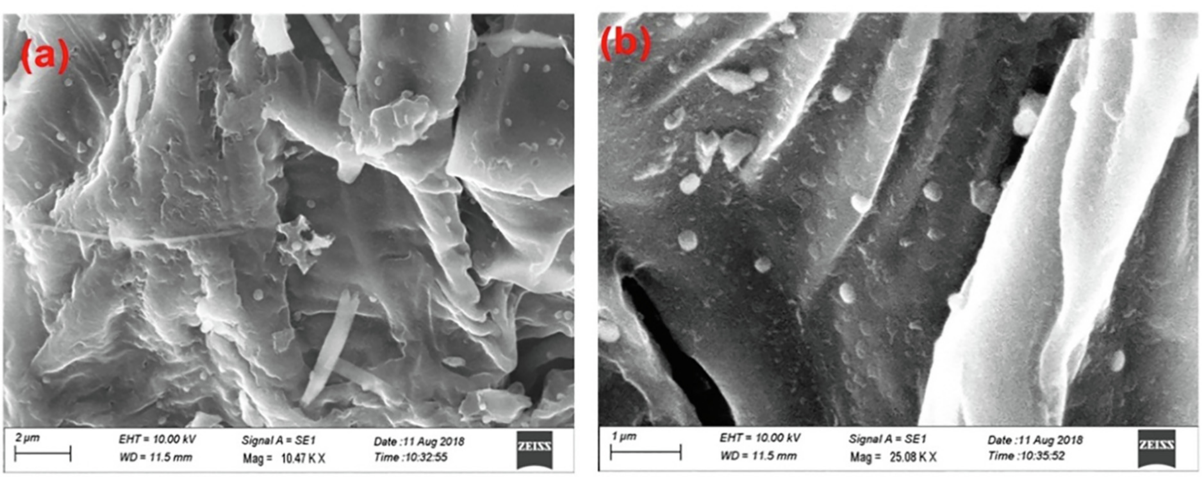

Fig. 1. (a) and (b) SEM images of orange waste peels carbon quantum dots. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

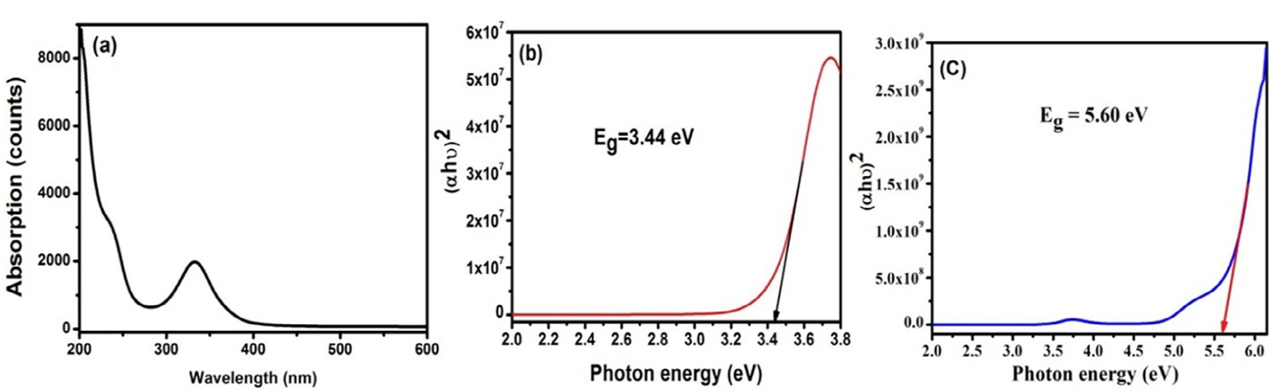

Fig. 2. (a) UV–vis absorption spectrum (b) Tauc's plot for energy bandgap 5.60 eV and (c) Tauc's plot for energy bandgap 3.44 eV (enlarged view).

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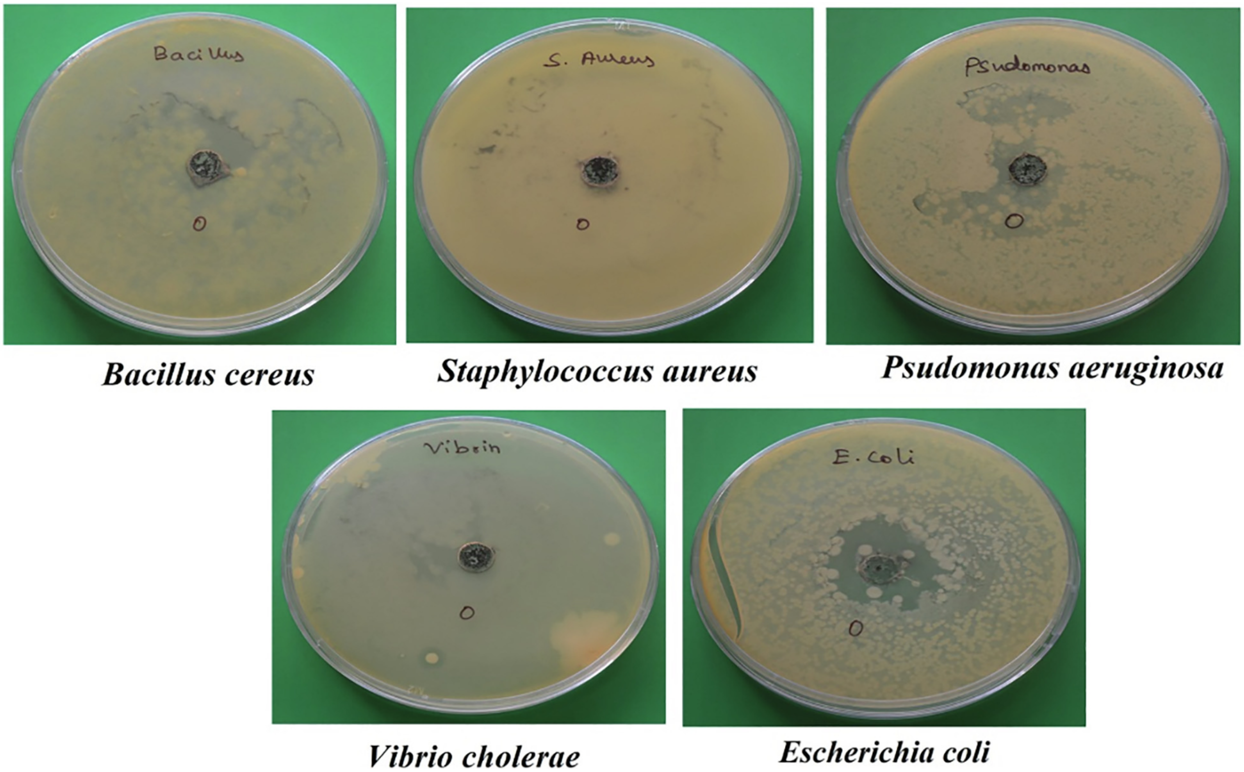

Fig. 3. Antibacterial activity plate photos of CQDs.

3.3. Antibacterial activity

The antibacterial activity of orange peel CQDs was tested against human pathogens gram-positive bacteria (*Bacillus cereus, Staphylococcus aureus*) and gram-negative bacteria (*Pseudomonas aeruginosa, Vibrio cholerae, Escherichia coli*) by agar diffusion technique. The growth of bacterial species can be found, by measuring inhibition zone around the holes. All the bacterial species growth on the surface of specimens was measured and its images are given in Fig. 3. The inhibition zone formed against gram-positive bacterial species are *Bacillus cereus* (17 mm), and *Staphylococcus aureus* (20 mm) and gram-negative bacterial species *Pseudomonas aeruginosa* an inhibition zone (31 mm), *Vibrio cholera* (13 mm), *Escherichia coli* (19 mm). It is known that if the diameter of the zone of inhibition is greater than 6 mm, it confirms the antibacterial activity but if the diameter is less than 6 mm the activity is weak [19].

However, the carbon quantum dots exhibit better antibacterial activity against *Pseudomonas aeruginosa* compared with other pathogens [20]. When bacterial cell infects the human cell, it leads to production of ROS, which is harmful to human health and affects DNA and causes cancer. The CQDs have contact with bacterial cells in the presence of moisture produce highly reactive oxygen species such as hydroxyl radicals, superoxide and that can penetrate the cell wall and lead to death bacterial death [21]. Table 1 shows the antibacterial activity of the as prepared CQDs compared with other some chemically prepared NPs or QDs. From the comparison table the CQDs showed good antibacterial agents [22]. The synthesized CQDs can be used in commercial medical and consumer products in near future.

Table 1
Antibacterial activity of orange waste peels carbon quantum (CQDs) was compared with various chemically prepared NPs and QDs.

Tested organism	Samples	Zone of inhibition (mm)	Ref.
Bacillus cereus	CQDs	17	Present work
	$NiFe_2O_4$@Ag	12	[18]
Staphylococcus aureus	CQDs	20	Present work
	Tamarind CQDs	10	[19]
	TiO_2	2.33 ± 0.33	[20]
Pseudomonas aeruginosa	CQDs	31	Present work
	$AgNO_3$	23	[21]
	TiO_2	1.67 ± 0.33	[20]
Vibrio cholera	CQDs	13	Present work
	CdO-MgO	12	[22]
Escherichia coli	CQDs	19	Present work
	Tamarind CQDs	12	[19]
	TiO_2	1.33	[20]

4. Conclusion

In summary, carbon quantum dots derived from orange waste peels by using simple hydrothermal approach. SEM analysis shows that the CQDs were agglomerated and has heterogeneous phase. The optical energy bandgap is 3.44 eV and 5.60 eV from UV – absorption spectrum. The CQDs has potential applications of optoelectronic device. The CQDs restricts the growth of five pathogens and has high antibacterial activity towards gram negative bacteria *(Pseudomonas aeruginosa)*. The encouraging results of the antibacterial activity suggested that the CQDs is a promising material for biomedical applications.

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CRediT authorship contribution statement

A. Lakshmanan: Conceptualization, Data curation, Formal analysis, Project administration. **P. Surendran:** Investigation, Methodology, Resources, Software. **N. Manivannan:** Data curation, Methodology, Formal analysis, Funding acquisition. **M. Sathish:** Methodology, Data curation. **C. Balalakshmi:** Writing - review & editing. **N. Suganthy:** Data curation, Conceptualization. **P. Rameshkumar:** Formal analysis, Software, Writing - review & editing. **K. Kaviyarasu:** Visualization. **G. Ramalingam:** Supervision, Validation, Writing - original draft, Writing - review & editing, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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