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A REVIEW ON CARBON DOTS PRODUCED FROM BIOMASS WASTE-ITS DEVELOPMENT AND BIO-APPLICATIONS

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ABSTRACT: Carbon nanomaterials belong to the carbonaceous family of less than 10 nm in size called Carbon dots (C-dots); the latest class of engineered nanoparticles has recently gained popularity for their unique characteristic features, such due to their low toxicity and miniature size, it can penetrate cells easily, thus becoming highly biocompatible. The advancement of science and its collaboration with multidisciplinary fields for developing C-dots, their characterization, and application into the faster, cheaper, and more reliable products in various scientific areas. C-dots synthesis uses biomass wastes because of their abundance, wider availability, low cost in terms of higher production rate, non-toxic and eco-friendly. Here biomass has been used as a carbon source from renewable raw materials, such as plant and animal derivatives, agricultural wastes, *etc*. This review aims to summarize the upgrading and recycling of biomass waste to produce C-dots, sources of biomass wastes, characterization of structure and composition, regulation of fluorescence, heteroatom doping, and its unique photoluminescence and chemiluminescence characteristics that make the C-dots most promising nanomaterial used for biological labelling, biological sensing, drug delivery, gene delivery, bioimaging, environmental monitoring, ion detections, biological labelling, biological sensing, drug delivery, gene delivery, and in agriculture also.

INTRODUCTION: In this era of nanotechnology, Carbon dots (C-dots) are the youngest member yet the most promising nanoparticles ever recognized by humanity. Recently, carbonaceous and carbon-based nanomaterials have gained traction in their properties as they are more intriguing than any other traditional quantum dots. These were first discovered by the laser ablation method.

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Carbon dots are biocompatible, cost-effective, less to/or non-toxic, water-soluble, extraordinary optical and electrochemical nanomaterials, also known as fluorescent carbons, because of their unique photoluminescent characteristics [1, 2, 3].

Carbon dots are composed of heteroatoms (like CO, NH_2, and OH) attached to a carbonized core. There are three classes of Carbon dots [1, 3].

- ✓ Carbon nanodots,
- ✓ Graphene quantum dots,
- ✓ Polymer dots.

There are two techniques commonly used for the synthesis of Carbon dots: Top-down and Bottom-up techniques. A bottom-up technique is preferable to a top-down technique because of its cost-effectiveness, low toxicity, eco-friendly with higher production rates, *etc* [3]. Recent approaches to Carbon dots preparation by the bottom-up method has been discussed in **Table 1**. The fabrication of Carbon Quantum Dots from neat carbon-containing sources such as citric acid, resorcinol, urea, and sugars, as well as from a variety of benign agro-based waste products including peel and leaves of lemon, watermelon shell, peels of cucumber and pineapple, and paper have made them particularly attractive in terms of reducing the environmental impact and the carbon footprint [2, 5].

For a long time, many metallic and non-metallic substances have been used to control microorganisms in agricultural fields to protect plants from bacterial and fungal diseases. Even though excessive use causes severe environmental problems, various pesticides, insecticides, and fungicides combat these plant diseases. Hence bio-safe, eco-friendly carbon-based nanomaterials have been utilized to improve the disease capability in plants. The current review aims to summarize the synthesis process of Carbon dot nanoparticles from biomass, its properties, and several applications such as bioimaging, biological sensing, toxicity determination, photocatalysis, antimicrobial activity, and many more [4].

Important Features of Carbon Dots: Carbon dots are commonly spherical, having an average diameter of <10 nm and consisting of sp^2 hybridised carbon core-shell between carbon (core) and organic functional groups (shell) such as N–H, –OH, –C=O, COOH, C−O, C–N or polymers. Sometimes, diamond-shaped structures are formed by sp^3 hybridised carbon atoms as well [1, 5, 3]. It has been studied that different techniques and sources can be employed in the synthesis of C- Dots to produce different structures. The functions allow C- Dots surfaces to be exposed with either hydrophilic or hydrophobic characters, which offer the requisite thermodynamic stability in various solvents, particularly in water. Carbon Dots surface modification by diverse functions, passivating agents, and solvents display a smart variation in their properties [1]. The size of C- Dots prepared by hydrothermal method using apple juice was 2.8nm, whereas vegetable peels was less than 5nm [6], [7]. The Carbon dots show significant effectiveness in the presence of UV-vis spectral analysis. The presence of π-π* (C=C) and n-π* (C=O, C-N, C-S, *etc.*) transition of double bonds, C- Dots absorbed in short wavelengths indicate the type of surface functional groups, routes of C- Dots synthesis, precursors and chemical environment. For example, the absorption bands of C- Dots at around 273 nm and 390 nm may imply sp^2 hybridization of the π-π* electrons and n-π* transition, respectively [1, 3, 8]. Again, combining the C- Dots with different nitrogen or nitrogenous groups may also influence the position of absorption bands.

The presence of heteroatoms (such as N, O, P, B, S, and Se) in the molecular structure also results in changes in the characterization of Carbon Dots[9]. For example, N-doped C-dots obtained from carboxymethylcellulose (CMC) of oil palm empty fruit bunches and linear structured polyethyleneimines (LPEI) show high fluorescence properties can be used to detect the presence of Cu^{2+} in real water [10]. The most interesting feature of C-dots is their tuneable photoluminescence (PL) properties arising from quantum effects. C-Dots with different colours can be synthesized, ranging from UV to infra-red, but most emit commonly from blue and green regions [11].

The heavy metal-doped Carbon Quantum Dots are 1-6 nm in size, and their photoluminescence improves with different emission wavelengths depending on the electro negativity of heteroatoms [12]. Photoluminescence from C-dots is possible only when the quantum yield of surface energy traps, which is involved in emission based on stabilization through surface passivation [13]. Hence C-dots are fabricated from different carbon sources by variable routes; the photoluminescence properties also depend on the size, solvent, pH, temperature, and so many. Different compositions of biomass can improve the fluorescence properties of C- Dots. Organic materials like peels of vegetables, fruits, and bark contain benzene, causing colouration in fruit and flowers. The presence of the benzene group may increase the conjugation degree of the system and easy to visualize the π-π* transition, thus enhancing the fluorescence of biomass C-Dots [9]. The source of C-Dots may affect the fluorescence properties, as it is obtained from pineapple peels degrade within a few weeks and fungal contamination was observed but same prepared from cucumber peels showed better stability and no fungal infection was observed and remained clear bright yellow solution for several months. Carbon dots have not been given any multicolour imaging because of their different chemical compositions, size, and heterogeneity. Chemiluminescence, defined as the production of light through a chemical method, is an important feature for future aspects of C- dot research. Due to its unique features like high sensitivity, no necessity for an external light source, the faster response time, it can be produced by an oxidation reaction or by indirect enhancing or inhibitory effects of certain luminescence compounds or by the reaction of the inorganic molecule [14], but its luminescence property will be weak because quantum yield is low [1]. Luminol, potassium permanganate, tris (2, 2-bipyridine) ruthenium (II) and peroxyoxalate are mostly used as chemiluminescence reagents in analytical applications [2]. For example, intense chemiluminescence of Carbon dots in the presence of $KMnO_4$ and cerium (IV) ions by forming a hole within the matrix of Carbon dots by various oxidants combined with electrons, which releases energy as CL (chemiluminescence). But these reagents have weaker CL intensity and are expensive and poisonous, which are their major drawbacks. Advanced research is currently going on by incorporating non-toxic, green, inexpensive fluorophores with a suitable candidate for enhancing the intensity of C-dots and increasing CL reaction for analytical applications [2]. The presence of nitrogen in C-dots has a remarkable effect on the chemiluminescence signal. Carbon nitride quantum dots (CNQDs) were found to have the most chemiluminescent intensity in the reaction system. Carbon dots are produced by doping with metal or non-metal elements such as nitrogen, sulphur, phosphorus, boron, copper, *etc.* in various combinations to improve the electrical, internal, and chemical properties of C-dots [2]. Nitrogen and sulphur co-doped C-dots have been synthesized from green tea leaves used in synthetic dye and cell imaging [15]. Biocompatible, water-soluble, low-cost Nitrogen-doped Carbon (N-CDs) dots are synthesized by the green electrochemical method which efficiently takes part in the plant growth regulation process [16]. The carbonaceous C-dots are more biocompatible than other nanomaterials as carbon constitutes the backbone of almost all the biomolecules. In low concentrations, most of the C-dots are naturally less toxic. This demonstrates that there is a negligible loss in cell viability and excellent biocompatibility for novel applications. For example, nitrogen (N) and sulphur (S) co-doped C-dots prepared from cellulose-based bio-waste highly influence quantum yield, low toxicity, biocompatibility, and successful bioimaging properties [5]. **Tables 1** and **2** have been given below to illustrate applications of Carbon dots in Photoluminescence (PL) and Chemiluminescence (CL) systems.

TABLE 1: CARBON DOT BASED PHOTOLUMINESCENCE DETECTION

Precursor materials	Synthesis route	Size	Applications
Citric acid, urea, thiourea	Microwave-assisted	10.0 nm	Mercury (II) and iodide detection [17]
Leaf extract of Bougainvillea	Microwave-assisted	10.7 nm	Bioimaging, detection of Cu (II) and red-emitting fluorescent ink [18]
Prickly pear cactus	Hydrothermal	5.6 nm	Arsenic (III) and hypochlorite ion detection in drinking water [19]
Alizarine carmine	Hydrothermal	2.37 nm	Detection of glutathione and cancer cell [20]

TABLE 2: CHEMILUMINESCENCE DETECTION OF CARBON DOTS

Precursor materials	Synthesis route	Size	Target of Detection
Ethylene glycol	Solvothermal	5.0 nm	Methoxyestradiol [21]
Phloroglucinol	Solvothermal	5.4 nm	Ascorbic acid [22]
L-cysteine and citric acid	Pyrolysis	3.1 nm	Carcinoembryonic antigen [23]
Citric acid, L-cysteine, and heteroatoms	Hydrothermal	10.0 nm	Oxytetracycline [24]

Synthesis of C-dots from Biomass Wastes: Biomass is a biodegradable, complex, heterogeneous, organic polymer including rich carbon, oxygen, nitrogen, sulphur, cellulose, hemicelluloses, starch, protein, metallic ions, *etc.* Thus, biomass waste is an ideal and renewable source of Carbon dots production as it is eco-friendly, biocompatible, cost-effective, and less toxic. Biomass waste can be sourced from agricultural wastes, domestic garbage, plant derivatives, animal husbandry, poultry farming, and municipal waste, *etc.* [9, 25]. Therefore, different raw materials of biomass wastes and their properties are discussed in the following **Table 3.**

TABLE 3: BIOMASS CARBON DOTS PREPARED FROM DIFFERENT SOURCES AND THEIR PROPERTIES [26]

Types of biomasses	Carbon source	Method	Product	Size (nm)	QY (%)	Colour or emission (nm)
Plants and their derivatives	Orange waste peels	Hydrothermal	Carbon Quantum Dots(CQDs)	2.9 ± 0.5	11.3	426
	Palm oil	-do-	-do-	5.0 – 7.0	24.6	440
	Cane sugar	Solvothermal	-do-	9.5 ± 1.9	5.2	-
	Green tea	Hydrothermal	-do-	5.0	12.0	658
	Mango leaves	Microwave	Graphene Quantum Dots (GQDs)	2.0 – 8.0	-	-
Animals and their derivatives	Cow milk	-do-	-do-	5.0	25.0	-
	Silk fibroin	-do-	CQDs	5.4 ± 0.9	15.0	blue
	Crab shell	-do-	-do-	4.0 ± 0.7	19.84	blue
	Eggs	Plasma	Carbon Dots	2.15	5.96	420
Municipal waste	Wastepaper	Hydrothermal	CQDs	2.0 – 8.0	-	420
	Organic waste	Photo-induced chemical reduction	-do-	2.0	-	450
	Sewage sludge	Chemical oxidation	GQDs	-	10.3	-

Microwave-assisted Method: It is a time-saving, energy-efficient, and eco-friendly method used to directly synthesize carbon dots. The main principle of this method is the carbonization of the small organic molecules by microwave heating for a very short time. Zheu *et al.* first reported the synthesis of Carbon dots by the microwave method from carbohydrates with unbelievable photophysical properties within a short period [27]. C-dots' photoluminescence and catalytic characteristics improved with this effective and localized heating technique. A large amount of effective, highly concentrated fluorescent C-dots was obtained from protein-rich egg-shell membranes [11, 28].

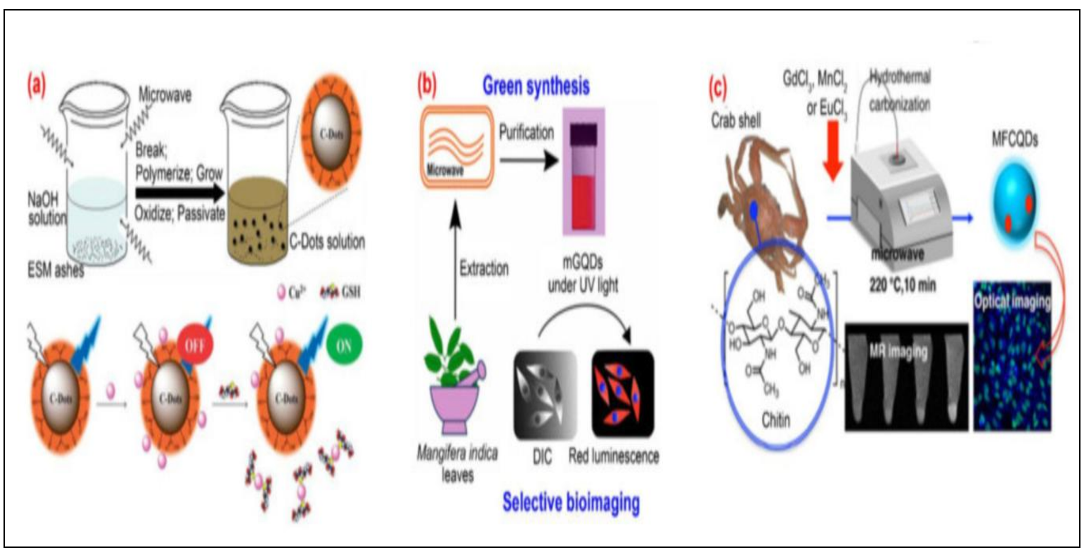

FIG. 1: PREPARATION OF FLUORESCENCE CARBON DOTS FROM BIOMASS WASTE BY MICROWAVE-ASSISTED METHODS. (A) THE PREPARATION AND APPLICATION OF C-DOTS FROM EGG-SHELL MEMBRANES [28]; (B) THE SYNTHESIS AND APPLICATION OF C-DOTS FROM MANGO LEAVES [11]; (C) THE PREPARATION AND APPLICATION OF C-DOTS FROM CRAB SHELL [2]

Earlier studies reported a simple one-pot microwave-assisted green synthesis method for producing Carbon Quantum Dots from *Mangifera indica* leaves extract, exhibiting independent fluorescent emission, fully cellular uptake, and temperature dependence [11]. Magneto-fluorescent Carbon Quantum Dots has been synthesized by using a waste crab shell and three metal ions, Gd^{3+}, Mn^{2+}, and Eu^{2+}respectively [29]. The prepared nanocomposite showed high cytotoxicity to the HeLa cell line. Several researchers worked on palm kernel shell biomass waste as an easily available precursor to prepare potential C-dots by microwave-assisted method, making an efficient role in cell imaging, detection, and removal of heavy metal ions (Cu^{2+}). Preparation of Carbon dots by microwave-assisted methods has been shown in **Fig. 1.**

Hydrothermal: This is the most stable method for synthesizing Carbon dots because of some excellent advantages such as non-toxicity, environment-friendly and minimum cost [30]. The main principle of this process is that the organic solutions (such as animal products, grass, food caramels, coffee seeds, orange juice, vegetable peels, *etc*) have been sealed in a hydrothermal synthetic reactor at a certain time with controlled temperature and pressure for the reaction to take place. Zhang *et al.* first reported the hydrothermal process to make Carbon Dots [27]. Lu *et al.* showed a simple, cost-effective, green synthesis methodology to produce C-dots with approximately 6.9% of quantum yield by the hydrothermal process using *Citrus maxima* peel waste material. Such explored C-dots have been used as probes for Hg^{2+} heavy metal detection. Pandiyan *et al.* reported that highly blue fluorescent and efficient Carbon Quantum Dots can be synthesized from biodegradable sugarcane bagasse pulp as industrial solid waste [32]. The antimicrobial activity of Carbon Quantum Dots has recently been discovered and directed against some gram-positive and gram-negative bacteria and is thus used as a substitute for conventional antimicrobial drugs. One-pot synthesis of Carbon dots from orange peel waste was produced using this process at mild temperature (180°C), where oxygen-rich ZnO conjugated C-dots were used to degrade naphthol blue-black azo dye under UV rays, which indicates its strong photocatalyst activity [33]. **Fig. 2**, as shown below, represents fluorescence preparation by the hydrothermal method.

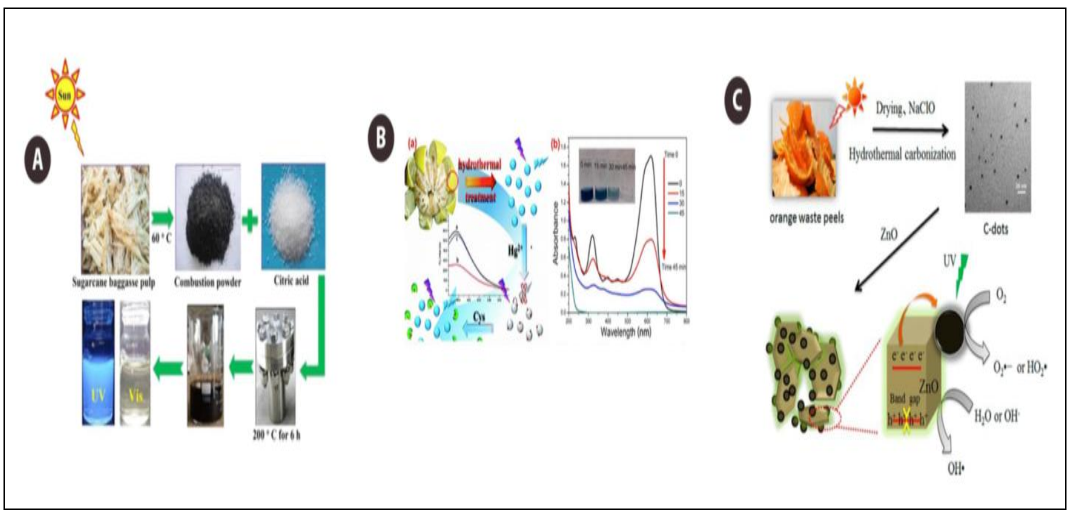

FIG. 2: PREPARATION OF FLUORESCENCE CARBON DOTS FROM BIOMASS WASTE BY HYDROTHERMAL METHOD. (A)THE PREPARATION AND APPLICATION OF C-DOTS FROM SUGARCANE BAGASSE PULP [32]; (B)THE PREPARATION AND APPLICATION OF C-DOTS FROM POMELO PEEL [31]; (C) THE PREPARATION AND APPLICATION OF C-DOTS FROM ORANGE PEEL [33]

Pyrolysis: It is a widely used approach to Carbon dots synthesis. The main principle of this method is that the carbon source is converted to Carbon Quantum Dots with the help of high/low temperature, dehydrations and carbonization in an inert atmosphere [25]. Highly concentrated alkaline materials are generally used in pyrolysis to synthesize Carbon dot nanoparticles. Zhou *et al.* produced large amounts of Carbon dots from watermelon peels as raw reproducible sources by the pyrolysis method [14]. The prepared C-dots were very small in size (2.0 nm), had blue luminescence and long-lasting fluorescence with good stability in pH 2.0-11.0. According to Xue *et al.,* green synthesis of strongly fluorescent, excitation dependent, highly fluorescent, photostable C-dots has been developed from peanut shells by this method [34]. It has been used as an effective fluorescent probe for living HepG2 cells imaging and to estimate cell viability [25]. Many waste materials are put in landfills and in thermal waste treatments that cause pollution and ash disposal. Many biomass pyrolysis products like biofuel and biogas are pollution-free, less toxic, and can produce bio-oil, biochar without air/oxygen. Some biodegradable industrial waste materials have been used to synthesize C-dots by this method to have low cytotoxicity to cells and can be used in cell imaging and anticancer drug discovery applications [25]. **Fig. 3** shows the pyrolysis method preparation of fluorescence Carbon dots from biomass waste.

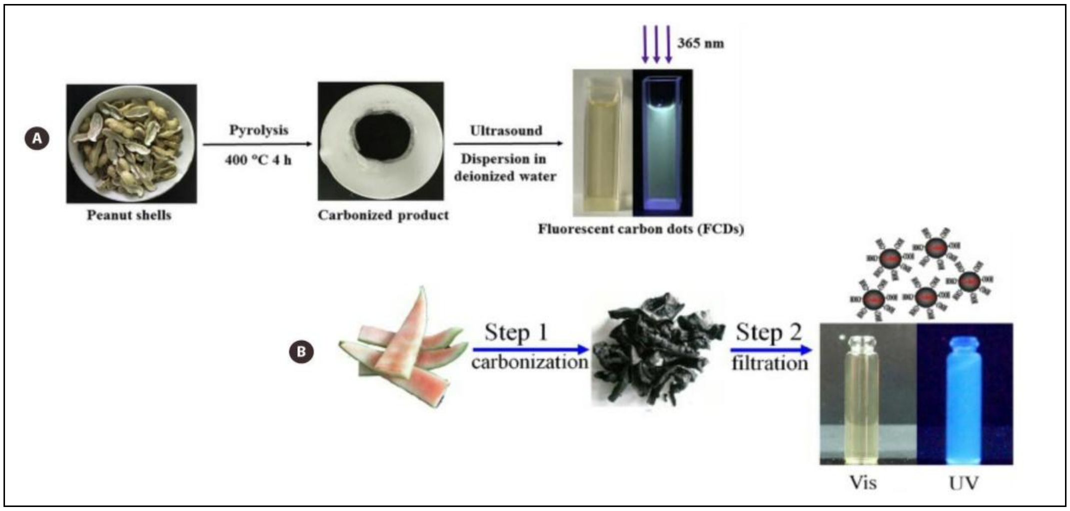

FIG. 3: PREPARATION OF FLUORESCENCE CARBON DOTS FROM BIOMASS WASTE BY PYROLYSIS METHOD. (A) THE PREPARATION AND APPLICATION OF C-DOTS FROM PEANUT SHELLS [34] (B) THE PREPARATION AND APPLICATION OF C-DOTS FROM WATERMELON PEELS [14]

TABLE 4: RECENT GREEN CARBON DOTS PRODUCED BY THE BOTTOM-UP APPROACH (HYDROTHERMAL, MICROWAVE-ASSISTED, AND PYROLYSIS) AND THEIR APPLICATION [2]

Synthetic approach	Source	Quantum yield (%)	Size range (nm)	λ_{em}Max	Application
Hydrothermal	Banana peel waste	5.0	4.0–6.0	355–429	Bioimaging
-do-	Cambuci juice	21.3	3.7	270, 283	Sensing of Zn^{2+}
-do-	Biomass waste	4.3–8.2	1.3 and 4.9	445, 435, 43, 435	Detection of Fe^{3+}
-do-	Biomass waste	14–3.5	6, 1.9 ± 0.3, 2.9, 0.7, 4.5	205, 260	Bio imaging
-do-	Broccoli	ND	2.0–6.0	330–470	Ag^{+} sensing
-do-	Lemon juice	79.0	4.5	540	Biosensors
-do-	Cherry tomatoes	9.7	7.0	430	Biosensors
Microwave-assisted	ND	26.0	~10.0	ND	Sensor of Hg^{2+} detection
-do-	Cotton linter waste	ND	10.1	420	Bioimaging
-do-	Quince fruit	8.6	4.9	450	Bioimaging
-do-	Roasted Chickpeas	1.8	4.5–10.3	435	Detection of Fe^{3+}
Pyrolysis	Chia seeds	ND	4.0	ND	Sensors

ND = Not Detected.

Application:

Toxic Chemical Detection in Foods: Toxic materials like heavy metal ions, antibiotics, and non-biodegradable chemicals in food cause serious health issues in the human body. Carbon dots (CD) based quenching sensors are ultrasensitive in detecting poisonous metal ions like copper, mercury, lead, cobalt, *etc*. Too much utilization of veterinary medications such as antibiotics in poultries may cause severe health issues in animals and birds. It can also cause high-level risk factors in animal-derived food like meat, milk and eggs [1,

[35]. Detection of the antibiotic residue by CD-based composite sensor where either PL quenching or enhancement was observed. Antibiotics or their residues like norfloxacin, oxytetracycline, chlortetracycline, tetracycline [36] etc. have been recognized from crude milk, egg, meat, and human urine samples. Oestrogen drugs that are utilized in animals and birds for quick development can be detected by CD-based sensors. The presence of microorganisms like *Escherichia coli*, *Bacillus subtilis*, *Listeria monocytogenes* [37,] and *Salmonella typhimurium* [38] in food is additionally distinguished by composite CDs. Other food additives such as sugar, nutrient, amino acids, and various colours utilised in food are recognized through CD-based sensors [27].

Chemical Sensor: Carbon dots-based sensors can be used to detect different chemicals. Jana *et al*. reported a composite logic gate sensor such as Carbon dots-MnO_2 for sensing low concentrations of NaAc (sodium acetate) and H^+ [27, 39]. This property of Carbon dots (CDs) is used for detecting different types of heavy metals [40] for example, Hg^{2+}, Ag^+, Cu^{2+}, Fe^{3+} *etc*. The heavy metal particle, Hg^{2+} is profoundly poisonous, and CDs are utilized for Hg^{2+} identification in a few events. The utilization of unmodified CDs for the recognition of Hg^{2+} and biothiols with higher selectivity and sensitivity has been newly introduced.

The expansion of Hg^{2+} to CDs causes fluorescence quenching. In any case, subsequent addition of biothiols to the Hg^{2+}, CDs recovered the fluorescence by the evacuation of Hg^{2+} ions, which have a high affinity towards thiol groups [41].

As per Wang *et al*. citric acid and amino acid-derived Carbon dots (CDs) gold nanoparticles (AuNPs) mixture for detecting Ag^+ particles in the presence of glutathione. They exhibited on the expansion of Ag^+ particles to a solution containing CDs-AuNPs and GSH. The solution colour changes from red to blue because of the aggregation of AuNP. This strategy could be utilized to distinguish Ag^+ particles with a detection breaking point of 50 nm [43].

Drug Delivery: Carbon dots can be utilized as a drug delivery agent because of their unique characteristics and safety for patients. The main principle behind drug delivery is that Carbon dot nanoparticles differentiate between tumour and healthy cells, and this specifies the use of Carbon dot nanomaterial-based drugs to deposit directly at a target site [3, 44]. The small size of Carbon dots permits quick cellular uptake of the drug activity, for example, the antitumor drug called doxorubicin was successfully loaded on the surface of the composite (arginine-glycine-aspartic acid-GQDs) and actively shows cytotoxicity against U^{251} glioma cells compared to free doxorubicin [39]. The pancreatic cancers (MiaPaCa-2 cells) were investigated by applying GQDS with biodegradable polystyrene vectors [15]. Kim *et al.* reported tumour ablation via chlorine (Ce6) loaded pH-sensitive Carbon dots (Ce6@IDCDs) [45]. The main outcome of nanoparticle-based drug delivery systems is that the drug's effectiveness is enhanced, and the patient's toxicity is reduced [44, 39].

Bio-Sensor: A fluorescent probe for trace amount detection of chemical and biological constituents, Carbon dots have been used as an analyst, which is new, efficient, and environment friendly. Different types of sensors are derived from Carbon dots which have been involved in identifying target elements like glucose, DNA, proteins, and heavy metals (Sn^{2+}, Cr^{6+}, Fe^{3+}, *etc.)*. Carbon dots are used to determine non-enzymatic blood glucose with the help of boronic acid [39].

The Carbon dot nanoparticles can detect the macro biomolecules such as amino acids, glucose, lipids, and intracellular ions like iron, copper, and phosphate. Nowadays Carbon Dots are also employed to measure the pH range of living cells [2, 27, 46].

Bio-imaging: Carbon dots are used in a method for imaging and direct visualization of biological processes in real-time with the help of optical features, which are often used to gain information on the 3D structure of the observed specimen from the outside. Different cell lines have been imaged by Carbon dots, such as Ehrlich ascites carcinoma cells, HepG2 cells, *Escherichia coli*, HeLa cells, and human lung cancer (A549) [39].

This is possible due to its fluorescent nature, high photobleaching resistivity, less cytotoxicity, and better aqueous solubility [3]. In the beginning, Ray *et al*. prepared the water-soluble, blue and yellow fluorescent Carbon dots from carbon soot and nitric acid. These prepared CDs entered the HepG2 cells and were used for bio-imaging [15].

Photocatalysis: Carbon dots can act as a catalyst in some reactions with the help of absorption spectrums, which have biological and environmental importance. Electron transfer with Carbon dots can be induced by photoexcitation because they are good electron donors and acceptors[32]. Due to their absorption and catalysis properties, they can easily coupled with other materials such as TiO_2, Fe_2O_3 or SiO_2 are appropriate for this application [47]. Nitrogen-doped empty Carbon dots show efficient visible-light photocatalyst degradation of methyl orange. It has also been reported that it shows good photocatalytic oxidation in the 1 - 4 nm range from benzyl alcohol to benzaldehyde in the presence of H_2O_2. Due to these reasons, Carbon dots are a great photocatalyst with strong absorption in the electromagnetic spectrum. The conversion under NIR light was observed to be 92–100%, confirming better redox properties [18].

Antimicrobial Activity: Carbon Dots can interact with different viruses, microbial activities and slow down infections. For example, Carbon dots attached with amino groups or boronic acid could affect the entry of the herpes simplex virus type 1 and stop its entry. Due to the COVID-19 pandemic outbreak, the potential use of Carbon dots in antiviral therapy (Coronavirus) has been introduced in advanced technology. Mechanistically, it may be due to the human coronavirus-229E entrance inhibition, caused by the interaction of the boronic acid functions of CDs with the HCoV229E S protein through pseudo-lectin-based interactions. Carbon dots have been used as an antimicrobial against different types of bacteria, including *Pseudomonas aeruginosa*, *Escherichia coli*, and *Staphylococcus aureus*, which cause diarrhoea, pus, burn infections, food poisoning and skin infections, respectively, and in the imaging of these microbes. Carbon dots can interact with gram-negative (*Escherichia coli*, *Klebsiella pneumoniae*) and gram-positive (*Staphylococcus aureus*, *Staphylococcus epidermidis*) bacteria. After absorption through their surface, it has been identified them by their high-intensity fluorescence emission [4]. Here the main function of such Carbon dots is due to the difference in surface charge and insertion of Carbon dots on the surface from long alkyl chains, which destroy the bacterial cell wall and inactivation the bacterial cell. Evaluation of microbial viability and image biofilm can be done using CDs [39].

Photodynamic Therapy: In photodynamic treatment (PDT) for cancer therapy, a photosensitive particle is used to create ROS (Reactive oxygen species) by moving energy consumed from the photons of a light source to molecular oxygen [46]. These photosensitive molecules should be deposited at or have the option to focus on the cells or tissue to get the treatment and where the light source is to be directed. At that point, these produced ROS then react with and separate the DNA of the objective cells from inducing cell death [44]. Ruthenium-containing CDs indicated that cancer cells created ROS when illuminated with white light and prompted photo-cleavage of cancer cell DNA[48]. By meeting every predetermined rule, these CDs demonstrated a capacity to be applied in PDT.

Detection of Explosives: Recognition and observation of explosives stand out in worry with public and worldwide security [49]. Picric acid, dynamite (TNT) and dinitrotoluene (DNT) are regularly recognized explosives whose presence even in following fixations demonstrates that they are life-threatening to humankind[50]. The recognition of these chemical compounds is difficult for analysts. Technologies which are used for their detection are too costly. CD-based composites are demonstrated to be helpful for their detection. A few reports observed where CDs are used for delicate detection of explosives with better proficiency, low cost, and minimal expense innovation [51]. Zhang *et al*. revealed amino-containing surface-created CDs that can potentially recognize TNT even at very low concentrations by the photoluminescence quenching method [52]. Tb-CD-composites developed with CDs and interesting earth metal terbium (Tb) are used for screening of picric acid and developed successfully.

SERS: SERS (Surface Enhanced Raman Spectroscopy) has been laid out as an exquisite analytical procedure to distinguish molecules at ultrasensitive concentrations down to a single molecule detection limit [53]. SERS spectra as obtained from dielectric molecular assay and surface plasmon materials are not viable because of the absence of appropriate interaction of the organic molecules with metals. Composite Carbon dots fixed these difficulties by acting as a mediator between the metal surface and probe molecules. Recently, Zhao *et al*. revealed Ag-CD composites obtained by combining N-CDs and Ag nanoparticles. The synthesized composites were utilized as logic gate sensors [54].

Optronics: Due to its low cost, eco-friendliness, high-quantum yield and low toxicity, Carbon dot nanoparticles are replacing traditional white light-emitting diodes, photocatalysts, and sensing applications. Carbon dots are a promising replacement of phosphor in diodes with toxic elements such as cadmium and lead [16]. It has also been used as a photosensitizer in solar cells, LEDs, electro-chemiluminescent Carbon dot-based LEDs [4].

According to Sarswat *et al*., due to electrochemiluminescence and photo-luminescence characteristics of Carbon dots obtained from food, beverage, and combustion waste, it has been subsequently used in the fabrication of light-emitting diodes [24]. Various applications of Carbon dots obtained from biomass waste have been given below in **Table 5.**

TABLE 5: MANY APPLICATION FIELDS OF CARBON DOTS OBTAINED FROM BIOMASS WASTE [25]

Application field	Biomass waste	Method	Application
Sensing	Bagasse waste	Hydrothermal	Hg^{2+} detection
	Crown daisy leaf waste	-do-	Cu^{2+} detection
	Ligno-cellulosic waste	-do-	Cu^{2+} detection
	Sargassum fluitans	-do-	DNA detection
Imaging	Onion waste	-do-	Multicolour imaging and Fe^{3+} detection
	Wheat straw and bamboo residues	-do-	Cell imaging and *in-vivo* bio-imaging *in-vivo* bio imaging
	Banana peel waste	-do-	Multicolour cell imaging and Fe^{3+} detection
	Lychee waste	Solvothermal	*In-vitro* cell imaging
Drug Delivery	Wheat bran	Hydrothermal	Drug delivery
	Sugarcane bagasse	Burn and Hydrothermal	Drug delivery vehicle for acetaminophen
	Waste sago bark	Catalyst-free pyrolysis	Anticancer drug delivery and cancer cell imaging
	Crab shells	Microwave	Drug delivery and targeted dual-modality bio imaging
	Bamboo leaves	Refluxing	Drug delivery and tumour imaging
Photocatalyst	Waste frying oil	Hydrothermal	Photocatalysis
	Orange peels	-do-	Photocatalysis
	Ligno-cellulosic waste	Pyrolysis	Photocatalysis coupled with pollutant utilization
	Bitter apple peels	-do-	Photocatalysis
	Lemon peel waste	Hydrothermal	Photocatalysis and sensing
Others	Waste food	-do-	Light-emitting diodes
	Willow leaves	-do-	Fluorescent ink and oxygen
	Pineapple peels	-do-	Reduction electro-catalysts
	Orange waste peels	-do-	Electronic security devices and as a memory element
	Tea and peanut shells	-do-	Nonlinear optical applications
	Sugarcane bagasse	Refluxes and hydrothermal	Tea grades discrimination

CONCLUSION: This review work is focused on the progress towards researching Carbon dots and their various importances in versatile fields such as biotechnology, agriculture, biochemistry, pharmaceutical and environmental factors. In recent times, research on Carbon dots has made massive progress. We mainly focused on the advantages of Carbon dots synthesis from the bottom-up process. It covers information about the current synthetic strategies of Carbon dots production. It has low cytotoxicity, a large surface area, good conductivity, and fast charge transfer potential for some great applications in the modern world. The development of fluorescence emitting Carbon dot-based sensors for monitoring herbs and some important crops like rice, wheat, *etc*. The main synthesis method of CDs is the hydrothermal method.

The morphology of carbon dots can be determined by spectro-fluorometer, TEM or Zeta sizer, UV-vis spectrophotometer, *etc*. High fluorescence quantum yield, good photostability, high photocatalytic activity, excellent biocompatibility, and low toxicity are CDs produced from biomass waste. The newcomer of the world of nanoscience has some mature applications in the field of chemical sensing, drug delivery, electrocatalysis, bio imaging, biosensors, and antimicrobial activities. A high amount of Carbon dots are synthesized at a low cost. These light-harvesting devices have high fluorescence properties and are urgently needed in future aspects of nanoscience. In the future, more studies will be needed to learn more intriguing aspects and novel applications of Carbon Dots in various fields.

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REFERENCES:

1. Bhartiyaa P, Singha A, Kumara H, Jain T, Singha BK and Dutta PK: Carbon dots: chemistry, properties and applications. Journal of the Indian Chemical Society 2016; 93: 759-766.
2. Das S, Ngashangva L and Goswami P: Carbon dots: an emerging smart material for analytical applications. Micromachines 2021; 12 (1): 84.
3. El-Shabasy RM, Elsadek MF, Ahmed BM, Farahat MF, Mosleh KN and Taher MM: Recent developments in carbon quantum dots: properties, fabrication techniques, and bio-applications. Processes 2021; 9 (2): 388.
4. Khayal A, Dawane V, Amin MA, Tirth V, Yadav VK, Algahtani A, Khan SH, Islam S, Yadav KK and Jeon BH: Advances in the methods for the synthesis of carbon dots and their emerging applications. Polymers 2021; 13(18): 3190.
5. Anuar NKK, Tan HL, Lim YP, Sufian M and Bakar NF A: A review on multifunctional carbon-dot synthesized from biomass waste: design/fabrication, characterization and applications. Front Energy Res 2021; 9: 626549.
6. Himaja AL, Karthik PS, Sreedhar B and Singh SP: Synthesis of carbon dots from kitchen waste: Conversion of waste to value-added product. J Fluoresc 2014; 24(6): 1767-73.
7. Mehta VN, Jha S, Basu H, Singhal RK and Kailasa SK: One-step hydrothermal approach to fabricate carbon dots from apple juice for imaging of mycobacterium and fungal cells. Sensors and Actuators B: Chemical 2015; 213: 434-443.
8. Wang X, Feng Y, Dong P and Huang J: A mini-review on carbon quantum dots: preparation, properties, and electrocatalytic application. Front Chem 2019; 7: 671.
9. Lou Y, Hao X, Liao L, Zhang K, Chen S, Li Z, Ou J, Qin A and Li Z: Recent advances of biomass carbon dots on syntheses, characterization, luminescence mechanism, and sensing applications. Nano Select 2021; 2(6): 1117-1145. DOI: 10.1002/nano.202000232.
10. Abdullah I M, Abidin Z, Sobri S, Rashid S, Adzir MM, Azowa IN and Pudza M: Facile synthesis of nitrogen-doped carbon dots from lignocellulosic waste. nanomaterials (Basel) 2019; 9(10): 1500.
11. Kumawat MK, Thakur M, Gurung RB and Srivastava R: Graphene quantum dots from *Mangiferaindica*: Application in near-infrared bio imaging and intracellular nanothermometry. ACS Sustain Chem Eng 2017; 5: 1382–1391.
12. Yoo D, Park Y, Cheon B and Park MH: Carbon dots as an effective fluorescent sensing platform for metal ion detection. Nanoscale Research Lett 2019; 14: 272.
13. Shafi A, Bano S, Sabir S, Khan MZ and Rahman MM: Eco-friendly fluorescent carbon nanodots: characteristics and potential application. Intech Open, chapter 8,2020,https://doi.org/10.5772/intechopen.89474.
14. Zhou JJ, Sheng ZH, Han HY, Zou MQ and Li CX: Facile synthesis of fluorescent carbon dots using watermelon peel as a carbon source. Mater Lett 2012; 66(1): 222–224.
15. Arul V and Sethuraman MG: Synthesis and characterization of heteroatom doped fluorescent carbon dots from edible sources and their catalytic and bio imaging applications, PhD Thesis, The Gandhigram Rural Institute Tamil Nadu, India 2019.http://hdl.handle.net/10603/315374.
16. Chen Q, Ren X, Li Y, Liu B, Wang X, Tu J, Guo Z, Jin G, Min G and Ci L: Promotion effect of nitrogen-doped functional carbon nanodots on the early growth stage of plants. Oxford Open Materials Science 2021; 1(1): 1 - 11.
17. Tabaraki R and Sadeghinejad N: Microwave-assisted synthesis of doped carbon dots and their application as green and simple turn off–on fluorescent sensor for mercury (II) and iodide in environmental samples. Ecotoxicol. Environ Saf 2018; 153: 101–106.
18. Bhati A, Raj AS, Saini D, Khare P, Dubey P and Kumar S S: Self-doped non-toxic red-emitting Mg–N-embedded carbon dots for imaging, Cu (II) sensing and fluorescent ink. New J Chem 2018; 42 (24): 19548–19556.

19. Radhakrishnan K and Panneerselvam P: Green synthesis of surface-passivated carbon dots from the prickly pear cactus as a fluorescent probe for the dual detection of arsenic (III) and hypochlorite ions from drinking water. RSC Adv 2018; 8 (53): 30455–30467.
20. Li L, Shi L, Jia J, Eltayeb O, Lu W, Tang Y, Dong C and Shuang S: Dual photoluminescence emission carbon dots for ratiometric fluorescent GSH sensing and cancer cell recognition. ACS Appl Mater Interfaces 2020; 12(16): 18250–18257.
21. Zhang M, Jia Y, Cao J, Li G, Ren H, Li H and Yao H: Carbon dots-enhanced luminol chemiluminescence and its application to 2-methoxyestradiol determination. Green Chem Lett Rev 2018; 11 (4): 379–386.
22. Zhu Q, Liu G, Yan MY J, Zhu L, Huang J and Yang X: Cu^{2+}enhanced chemiluminescence of carbon dots- H_2O_2 system in alkaline solution. Talanta 2020; 208 (1): 120380.
23. Cao JT, Zhang WS, Wang H, Ma SH and Liu YM: A novel nitrogen and sulfur co-doped carbon dots- H_2O_2 chemiluminescence system for carcinoembryonic antigen detection using functional HRP-Au@Ag for signal amplification. Spectrochim. Acta Part A Mol Biomol Spectrosc 2019; 219: 281–287.
24. Amjadi M, Hallaj T and Mirbirang F: A chemiluminescence reaction consisting of manganese (IV), sodium sulfite and sulfur and nitrogen-doped carbon quantum dots, and its application for the determination of oxytetracycline. Microchim. Acta 2020; 187: 191.
25. Kang C, Huang Y, Yang H, Fang YX and Chen ZP: A review of carbon dots produced from biomass wastes. Nanomaterials 2020; 10(11): 2316.
26. Ang WL, Boon Mee CAL, Sambudi NS, Mohammad AW, Leo CP, Mahmoudi E, BaAbbad M and Benamor A: microwave assisted conversion of palm kernel shell biomass waste to photoluminescent carbon dots. Sci Rep 2020; 10(1): 21199.
27. Gayen B, Pal C S and Chowdhury J: Carbon dots: a mystic star in the world of nanoscience. Journal of Nanomaterials 2019; Article ID 3451307: 19.
28. Wang Q, Liu X, Zhang L C and Lv Y: Microwave-assisted synthesis of carbon nanodots through an egg-shell membrane and their fluorescent application. Analyst 2012; 137(22): 5392–5397.
29. Yao YY, Gedda G, Girma WM, Yen L, Ling YC and Chang JY: Magnetofluorescent carbon dots derived from crab shell for targeted dual-modality bioimaging and drug delivery. ACS Appl. Mater. Interfaces 2017; 9(16): 13887–13899.
30. Sharma A and Das J: Small molecules derived carbon dots: synthesis and applications in sensing, catalysis, imaging, and biomedicine. J Nanobiotechnol 2019; 17(1): 92.
31. Lu WB, Qin XY, Liu S, Chang GH, Zhang YW, Luo YL, Asiri AM, Al-Youbi AO and Sun XP: Economical, green synthesis of fluorescent carbon nanoparticles and their use as probes for sensitive and selective detection of mercury (II) ions. Anal Chem 2012; 84(12): 5351–5357.
32. Pandiyan S, Arumugam L, Srirengan S K, Pitchan RK, Sevugan P, Kannan K, Pitchan G, Hegde TA and Gandhirajan V: Biocompatible carbon quantum dots derived from sugarcane industrial wastes for effective nonlinear optical behavior and antimicrobial activity applications. ACS Omega 2020; 5(47): 30363–30372.
33. Prasannan A and Imae T: One-pot synthesis of fluorescent carbon dots from orange waste peels. Ind Eng Chem Res 2013; 52(44): 15673–15678.
34. Xue MY, Zhan ZH, Zou MB, Zhang LL and Zhao SL: Green synthesis of stable and biocompatible fluorescent carbon dots from peanut shells for multicolour living cell imaging. New J Chem 2016; 40(2): 1698–1703.
35. Zhou JW, Zou XM, Song SH and Chen GH: Quantum dots applied to methodology on detection of pesticide and veterinary drug residues. Journal of Agricultural and Food Chemistry 2018; 66 (6): 1307–1319.
36. Yang X, Luo Y, Zhu S, Feng Y, Zhuo Y and Dou Y: One-Pot synthesis of high fluorescent carbon nanoparticles and their applications as probes for detection of tetracyclines. Biosensors Bioelectronics 2016; 56: 6–11.
37. Zhong D, Zhuo Y, Feng Y and Yang X: Employing carbon dots modified with vancomycin for assaying gram-positive bacteria like *Staphylococcus aureus*. Biosensors Bioelectronics 2015; 74: 546–553.
38. Wang R, Xu Y, Zhang T and Jiang Y: Rapid and sensitive detection of *Salmonella typhimurium* using aptamer-conjugated carbon dots as fluorescence probe. Analytical Methods 2015; 7(5): 1701–1706.
39. Liu J, Li R and Yang B: Carbon Dots: a new type of carbon-based nanomaterial with wide application. ACS Cent Sci 2020; 6(12): 2179−2195.
40. Sharma V, Tiwari P and Mobin SM: Sustainable carbon-dots: recent advances in green carbon dots for sensing and bioimaging. J Mater Chem B 2017; 5(45): 8904–24.
41. Zhou L, Lin Y, Huang Z, Ren J and Qu X: Carbon nanodots as fluorescence probes for rapid, sensitive, and label-free detection of Hg^{2+} and biothiols in complex matrices, Chem. Commun 2012; 48(8): 1147–9.
42. Lin X, Gao G, Zheng L, Chi Y and Chen G: Encapsulation of strongly fluorescent carbon quantum dots in metal-organic frameworks for enhancing chemical sensing. Anal Chem 2014; 86(2): 1223–8.
43. Wang F, Lu Y, Chen Y, Sun J and Liu Y: Novel colorimetric nanosensor based on the aggregation of Au-NP triggered by carbon quantum dots for detection of Ag^+ ions. ACS Sustain Chem Eng 2018; 6(3): 3706–13.
44. Jorns M and Pappas D: A review of fluorescent carbon dots, their synthesis, physical and chemical characteristics, and applications. Nanomaterials 2021; 11 (6): 1448.
45. Kim D. H, Seo J and Na K: pH-sensitive carbon dots for enhancing photomedicated antitumor immunity. Mol Pharm. 2020; 17 (7): 2532–2545.
46. Zuo J, Jiang T, Zhao X, Xiong X, Xiao S and Zhu Z: Preparation and application of fluorescent carbon dots. Journal of Nanomaterials 2015; Article ID 787862: 1-13.
47. Sciortino A, Cannizzo A and Messina F: Carbon nanodots: a review from the current understanding of the fundamental photophysics to the full control of the optical response. J. of Carbon Research 2018; 4(4): 67.
48. Yue L, Li H, Sun Q, Zhang J, Luo X, Wu F and Zhu X: Red-emissive ruthenium-containing carbon dots for bioimaging and photodynamic cancer therapy. ACS Appl. Nano Mater 2020; 3(1): 869–876.
49. Kumar S, Venkatramaiah N and Patil S: Fluoranthene based derivatives for detection of trace explosive nitroaromatics. J. of Physical Chemistry 2013; 117(14): 7236–7245.
50. Tenhaeff WE, McIntosh LD and Gleason KK: Synthesis of poly (4 vinylpyridine) thin films by initiated chemical vapour deposition (iCVD) for selective nanotrench-based sensing of nitroaromatics. Advanced Functional Materials 2010; 20 (7): 1144–1151.
51. Chen BB, Liu ZX, Zou HY and Huang CZ: Highly selective detection of 2, 4, 6-trinitrophenol by using newly

developed terbium-doped blue carbon dots. Analyst 2016; 141(9): 2676–2681.

52. Zhang LL, Han YJ, Zhu JB, Zhai YL and Dong SJ: Simple and sensitive fluorescent and electrochemical trinitrotoluene sensors based on aqueous carbon dots. Analytical Chemistry 2015; 87(4): 2033–2036.
53. Zivanovic V, Kochovski Z, Arenz C, Lu Y and Kneipp J: SERS and cryo-EM directly reveal different liposome structures during interaction with gold nanoparticles. J of Physical Chemistry Letters 2018; 9(23): 6767–6772.
54. Su Y, Shi B, Liao S, Zhao J, Chen L and Zhao S: Silver nanoparticles/N-doped carbon-dots nano-composites derived from *Siraitia grosvenorii* and its logic gate and surface-enhanced raman scattering characteristics. ACS Sustainable Chemistry and Engineering 2016; 4(3): 41728–1735.

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