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Advancing Food Industry with Quantum Dot Technology

Sunanda Mondal[1*]
M. Tech Scholar, Food Plant Operations Management,
National Institute of Food Technology
Entrepreneurship and Management,
Sonipat, India

Vimal Pant[2]
Head Of Department of Food Business Management and Entrepreneurship Development, National Institute of Food Technology Entrepreneurship and Management,
Sonipat, India

Sayantani Mondal[3]
PhD Scholar, Dairy Technology Division,
National Dairy Research Institute, Karnal

Corresponding Author: Sunanda Mondal[1*]

Abstract:- Since people consume different varieties of food, they are more conscious of their health nowadays. Food analysis, which is a major element, helps to monitor the food quality for risk assessment regarding public health. As Carbon Quantum Dots (CQDs) are the least toxic, they are in great demand. They help to optimize food packaging, detect as well as monitor foodborne pathogens, and assess food quality utilizing imaging and sensing. Owing to their nontoxicity and eco-friendliness, CQDs stand unique although there are different kinds of Quantum Dots (QDs). To enhance food safety, quality assessment, and packaging, CQDs also deliver exciting possibilities. CQD applications can detect insecticide residues, antibiotics, nutrients, heavy metals, pathogens, and food additives. Furthermore, CQDs find use in food packaging materials in which their Ultraviolet (UV) barrier, antimicrobial, and antioxidant properties increase product shelf life and decrease food waste. Hence, explaining CQDs' industrial applications in the food sector is the study's objective. In this paper, CQDs' role in food processing and its industrial applications in food sectors, including food detection and packaging are explored.

Keywords: *Quantum Dots, Carbon Quantum Dots, Food Sector, Heavy Metals, Pathogens And Contaminants.*

I. INTRODUCTION

Among people, awareness to concentrate on health has been increasing in recent years owing to their superior development in living standards. In general, the basic need in life is food. One of the basic human rights is food safety, and supplying it helps to optimize human health, which enhances the length and quality of people's lives [1]. But, the most challenging things among food safety problems are antibiotics (contaminants) and pesticides (contaminants) [2]. Nanotechnology plays a significant role in increasing food security and safety although various conventional techniques have exhibited accurate outcomes for food detection. Some of the energy-efficient nanomaterials, which are developed to note down the variation in the quality of packaged foods, are carbon-based materials and metallic nanoparticles. But, distinct fluorescent nanomaterials like QDs, which are made of inorganic material or heavy metal, are semiconductor nano-sized particles. In the food sector, **CQDs** have an exceptional place among various types of QDs owing to their distinct properties and applications [3]. CQDs are quasi-spherical particles that are less than 10 nm in size with significant physicochemical features, such as high photostability, low toxicity, chemical inertness, inexpensive, and biocompatibility [4]. CQDs possess various applications, namely food packaging and food detection in the food industry [5]. Different types of sources used in the carbon dots fabrication for active food packaging applications are explained in Figure 1.

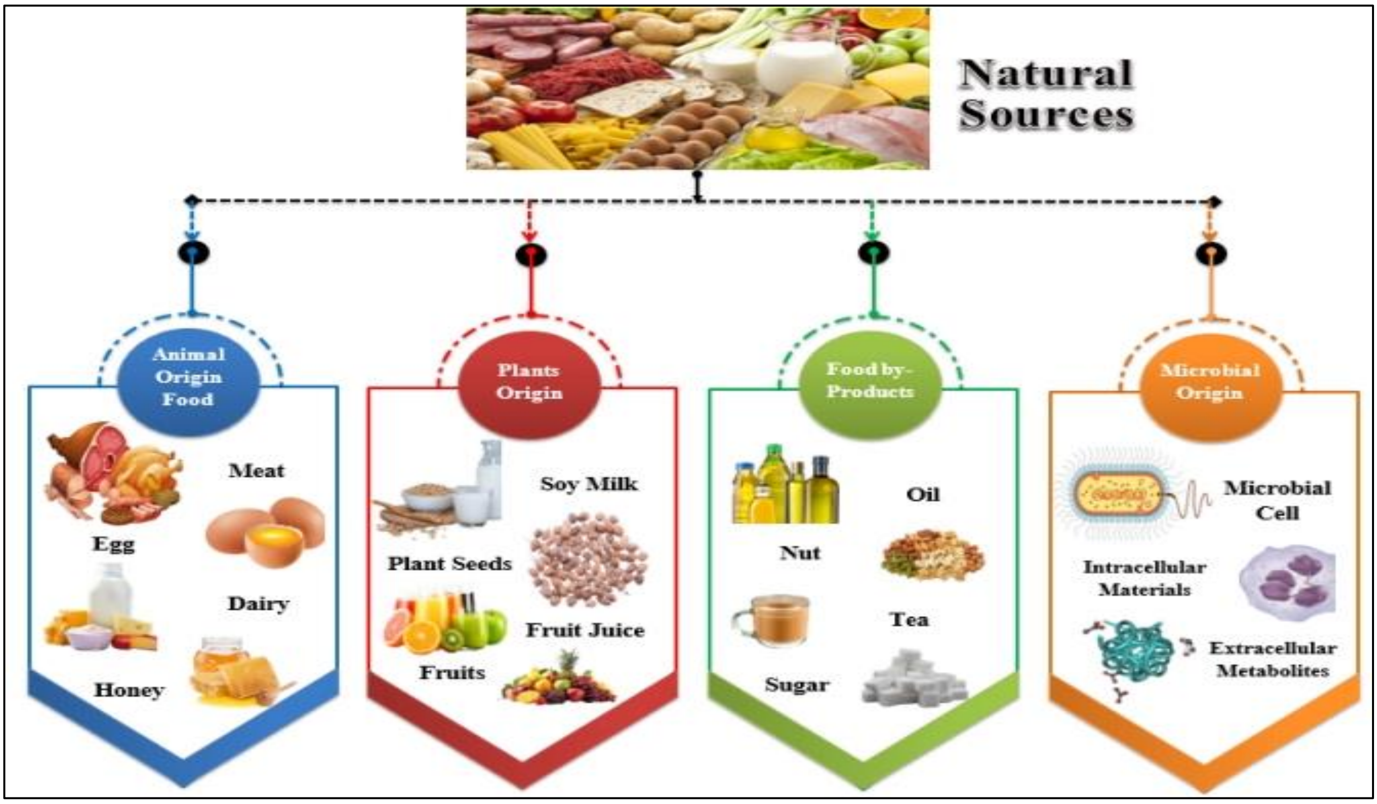

Fig 1: Different Sources Utilized for the Fabrication of CQDs for Active Food Packaging Applications

In the food industry, CQDs have important internal applications, particularly in the scope of food packaging, food safety, and food detection. To increase product shelf life as well as safety, CQDs are merged into the respective materials in the food packaging area. CQDs can identify heavy metals [6] and pathogens [7] and help to monitor antibiotic residues in the food detection area. Moreover, CQDs have different properties that make them more fit for food safety.

After the introduction (**"Section 1")**, the paper's structure is arranged as: **"Section 2"** presents the research questions to make the review more clear. The literature survey for CQDs' industrial application in the food sector is explained in **"Section 3". "Section 4"** describes the summary of the study to know the outcomes attained via the study. Lastly, **"Section 5"** ends the survey with suggestions and future recommendations.

II. RESEARCH QUESTIONS

In a systematic review, a Research Question (RQ) is essential. Before entering into the research, designing a well-structured research question is important. To make the review paper more creative, the following questions must be answered.

- What is the role of CQDs in food processing?
- What are CQDs' industrial applications in the food sector?
- What is CQDs' importance in the food packaging application?
- What are the related studies of CQDs in food detection?

III. LITERATURE REVIEW ON INDUSTRIAL APPLICATION OF CARBON QUANTUM DOTS IN THE FOOD SECTOR

For diagnosis of residual toxicants in agricultural, environmental, and food samples, CQDs are found to be fit since they examined their normal operation, higher sensitivity, large surface area, and nanoscale size.

Thus, this review paper is created to contribute to the CQDs' role in food processing as well as CQDs' industrial applications in the food sector, including food packaging and food detection.

A. CQDS' Role in the Food Processing

Similar to the 'farm-to-table' strategy, CQDs should monitor as well as take care of food production quality at all stages [8]. Moreover, CQDs are generally named carbon nanodots. They are more efficient in guaranteeing food safety. In addition, CQDs can identify insecticide residues, heavy metals, pathogens, and food additives [9].

Fatemeh, *et al.* [10] described the Fluorescent turn-on sensing of Caffeine in food samples based on Sulfur-doped CQDs (S-CQDs) through the Response Surface Methodology. S-CQDs were integrated using the microwave-assisted treatment. The outcomes indicated that with caffeine's enhancing concentrations from 0.2 µM to 70 µM, the model's fluorescence intensity enhanced.

Achilleas, *et al.* [11] analyzed the N/S-CQDs' growth as well as characterization by validating Greek Crayfish Food Waste. Instrumental and chemical techniques were utilized to characterize the final product. As per the analysis, Nitrogen co-doped CQDs (N/S-CQDs) provided superior outcomes since the coated strawberries sustained their color as well as weight for 3 successive days.

Jungbin, *et al.* [12] explained the food waste-driven N-doped carbon dots with cell imaging as well as Fe3+ sensing applications. For analyzing CQDs' chemical transition, food waste-driven cat feedstocks were used. Outcomes indicated that similar to the waste model having 28% quantum yield, food waste-driven CQDs had the same chemical as well as fluorescent properties.

B. *Industrial Application of CQDS in Food Sector*

Enhancing food sustainability, quality, and safety is the purpose of investigating CQDs' industrial applications in the food sector. Some of the important CQD applications in the food sector are food packaging and food detection.

➢ *Food Packaging*

In food packaging, CQDs have the most significant role as well as possess a wide range of potential applications. For preserving the freshness and quality as well as increasing the shelf-life of the food, CQDs help in creating new biodegradable anti-oxidation, antibacterial, and biocompatible films for food packaging.

Melis, *et al.* [13] described the CQDs as Edible Food Packaging Films and Coatings with antimicrobial as well as UV-blocking properties. From the location of Sigma-Aldrich, the material named Polyethylene Glycol (PEG) as well as urea were gathered. According to the findings, for the growth of edible coatings along with packages, CQDs were used together with their use in the pharmaceutical and healthcare applications and the food industry.

Zifan, *et al.* [14] explained the Nitrogen-doped CQDs (N-CQDs) with the synthesis by utilizing the solvothermal approach. N-CQDs were used to detect the trace of Ag+ in food packaging material. Analysis indicated that Ag+ was robustly and correctly detected by N-CQDs, which were found to be a promising tool for the detection of Ag+ traces in food packaging materials.

Yuqing, *et al.* [15] established the edible antibacterial film preparation based on Corn Starch /Carbon Nanodots (CS-CNDs) for bioactive food packaging. Analyzing the CS's antimicrobial, antioxidant, and physical properties regarding CQDs is the objective. The outcomes displayed that in developing accessible films for packaging food items, adding low concentrations of CQDs with CS indicated evident outcomes.

➢ *Food Detection*

CQDs, which could be used to detect food ingredients and contaminants, are a type of photoluminescent nanomaterial [16]. Furthermore, CQDs could be utilized for detecting food additives, pathogens, heavy metals, Insecticide and antibiotic residues, as well as Nutritional components [17]. In the pathogens' detection, carbon dots-centric biosensors are chosen owing to their higher sensitivity and selectivity in the food sector [18]. Detection Limit (DL), Limit Of Quantification (LOQ), and Relative Standard Deviation (RSD) are the parameters used in the findings. Table 1 illustrates some of the CQD research papers in food detection with its specimens, samples, and outcomes.

Table 1: Studies of CQDs in Food Detection with Specimens, Samples and Outcomes

Author Name	**Specimen**	**Aim**	**Food Samples**	**Findings**	
				DL	**RSD**
Chunhao, et al. [19]	Not mentioned	To identify residues from leafy vegetables using CQDs	Leafy vegetables	0.00187 mg/kg	0.001 and 0.027%
Xuetao, et al. [20]	Melamine	Identifying melamine in milk on the basis of gold doped CQDs	Milk	0.0036 µm (3.6 nM)	LOQ 12 nM
Yuanyuan, et al. [21]	Tetracycline	To identify Tetracycline in foods on the basis of CQDs	Natural red beet	0.36 µm	Not mentioned
Ziting, et al. [22]	Tetracycline	Identifying Tetracycline in foods on the basis of Cerium-doped CQDs	Milk and pork	0.25 µm	Not mentioned
Wenting, et al. [23]	4-nitrophenol	To identify 4-nitrophenol in foods on the basis of Silane-functionalized CQDs	Fish	23.45 nmol·L1	RSD Lower than 5%

Guangxin, *et al.* [24] explained the Ratiometric Fluorescence Immunoassay based on CQDs to diagnose Malachite Green in Fish. Horseradish peroxidase was used to transform o-phenylenediamine to 2, 3-diaminophenazine. As per the analysis, the detection limit was found to be 0.097 µg·kg−1. Moreover, the RSDs were found to be less than 3%.

Chunling, *et al.* [25] described CQDs established from chicken blood as peroxidase mimics for biothiols' colorimetric detection. The traditional colorimetric method was utilized for identifying biothiols using CQDs. The outcomes displayed that 0.9, 0.6, and 0.4 µM were the Limit of Detection (LoD) of Homocysteine (HcySH), Glutathione

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(GSH), and CySH. Moreover, RSD was between 1.0% and 4.3%.

IV. SUMMARY OF THE STUDY

Worldwide, the food industry is the largest industry that contributes to the supply of food energy for the world population. Quality assessment and safety control are found to be most significant in the food sector. For identifying different components like nutrients, heavy metals, additives, as well as insecticide residues in food, CQDs are used. Here, a mini review on the industrial application of CQDs in the food sector has been provided. 4 RQs, such as RQ I, RQ II, RQ III, and RQ IV are addressed in the study:

- **Role of CQDs in food processing (RQ I):** This question intends to explain the role of CQDs in food processing regarding the objective, and it is explained in section 3.1.
- **Industrial applications of CQDs in the food sector (RQ II):** The objective here is to describe the industrial applications of CQDs in the food sector, and this information is presented in Section 3.2.
- **Importance of CQDs in the food packaging application (RQ III):** RQ3 aims to explain the significance of CQDs in the food packaging application as described in Section 3.3.1.
- **Kind of role played by CQDs in the food safety application (RQ IV):** The role played by CQDs in the food safety application is mentioned through different studies in section 3.2.2.

Thus, numerous benefits are produced by adding CQDs to packaging materials. Via antioxidant properties, the shell life can be extended. By maintaining freshness, food waste can be reduced. For preserving food quality, CQDs aid in converting packaging into a dynamic tool. Thus, in this work, valuable insights are delivered into CQDs' evident role regarding the food sector, and the foundation for practical applications as well as further research in its associated fields is laid.

V. CONCLUSION

Here, the CQDs' industrial applications in the field of the food sector are illustrated. CQDs serve as sensitive and accurate fluorescence sensors that detect contaminants, additives, and pathogens. Examining CQDs' potential, which prevented harmful substances from entering the food supply chain, enabled the creation of robust safety protocols. Ensuring safer, more sustainable, and technologically advanced food processing practices is the purpose of examining CQD applications in the food industry. But, for further enhancing the safety in the food sector using CQDs, more research is required. The major limitation is that there will be environmental health risks of CQDs, particularly their long-term effects, biodegradability, and bioaccumulation. These limitations must be noted and better solutions should be found by researchers in the future study. Here, key research questions are also addressed, which sheds light on the food plant operation categories. These insights render valuable guidance in understanding the CQDs regarding the food sector broadly. An important milestone is marked by the research, which establishes a foundation to advance the food sector.

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