Smartphone-Based Fluorescence Nanosensor Using Green-Synthesized Carbon Quantum Dots for On-Site Melamine Detection in Milk

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Abstract - Melamine adulteration in milk is a significant global food safety problem that requires fast, inexpensive, and field-deployable detection technologies. Standard analytical techniques used for detection are accurate; however, they may not be applicable for responding to growing concerns about melamine contamination because they relied on highly expensive analytical equipment, overly complicated instrumentation, or central laboratory requirements for testing and analysis. This article outlines an original framework for a portable, smartphone-assisted detection platform of melamine using environmentally friendly synthesized CQDs. When synthesized from renewable feedstocks, CQDs exhibit stable fluorescence while selectively quenching fluorescence when exposed to melamine, allowing for visual readouts with a simple setup under UV excitation. The primary challenge to the operational feasibility of CQD testing in the field will be the development of mobile formats, including a dry-format test strip. We envision a test strip housed in a small dark box containing a UV-LED source; the user will be directed to capture a photo of the test strip under UV excitation with their smartphone camera. The fluorescence signals captured via the camera would then be processed through an AI-enhanced algorithm that estimates the concentration of melamine. At the forefront of our model is the sustainability of the environment, user-friendly, minimal technical training, and field-based capacity. By merging green nanotechnology, mobile sensing, and machine learning or artificial intelligence analysis, the framework aims for decentralization while flourishing sustainable food quality monitoring. The proposed framework is extensible to other food contaminants and exemplifies a new paradigm of accessible diagnostics for the developing world.

Keywords - Smartphone Sensing, Carbon Quantum Dots, Green Synthesis, Melamine Detection, Fluorescence Quenching, Sustainable Nanotechnology, and On-site Food Monitoring.

I. INTRODUCTION

Milk is a fundamental food product around the world, particularly for children and at-risk populations, but its safety is always at risk when it is not contaminated. One of the most concerning adulterants is melamine, a nitrogen-heterocyclic compound modified for industrial uses and illegally added to give a misleading higher protein content. The melamine crisis in China in 2008, which resulted in over 300,000 cases of illness and infant mortality, demonstrated the failure and lack of a quality assurance system in dairy, leading to changes in regulations throughout the world. Even with changes in regulations, there are still a number of issues with the milk supply chain, especially when working with a decentralized system that involves rural components. In addition, without good-quality analytics to detect contaminants in real-time, stopping diluted products from reaching consumers simply is not possible.

Current detection methods for melamine, including High-Performance Liquid Chromatography (HPLC), Gas Chromatography Mass Spectrometry (GC-MS), and Enzyme-Linked Immunosorbent Assay (ELISA), remain the gold standard in analytical testing. However, they rely on centralized laboratories with associated high operating costs, while needing normative training to be fully effective as tools in the field. The field continues to lag the capabilities of the laboratory, leading to longer time experiences before diagnosing consumers' needlessly interacting with dangerous products. Recent advances in nanotechnology and green chemistry have provided opportunities for rethinking how melamine testing might take place in the field settings. CQDs are fluorescent nanomaterials derived from biowaste sources that provide a compelling mix of biocompatibility, tunable optical properties, and environmental sustainability as a test option for dairy contaminants. This potential has not been fully explored and is still constrained by variations in fluorescence, signal interpretive difficulties, and a lack of interrogation with handheld devices and other portables.

This article proposes a conceptual framework for a nanosensing platform integrated with smartphone functionality that uses green-synthesized CQDs for on-site melamine detection in milk. The proposed platform combines dry-format CQD test strips with a standardized compact imaging chamber with UV-LED excitation. The image captured via smartphone, and the quantification of the signal is automated using a model that uses convolutional neural networks based on metrics related to fluorescence intensity and spatial distributions. This article represents more than just a technical solution. It represents a coherent design logic that incorporates sustainable materials, mobile computing, and low-cost manufacturing. The aim is not only a form of food safety detection, but to democratise food safety diagnostics to be participatory and accessible to farmers, cooperatives, and consumers. The conceptual model here extends beyond melamine, also providing a scalable platform for the detection of food contaminants to work globally in low-resource settings. This will contribute to a future of smart, decentralized, and sustainable food quality monitoring.

II. LITERATURE REVIEW

Melamine detection methods have been developed in recent decades to satisfy the need for fast, sensitive, and economical detection methods to safeguard food quality, especially found in milk and dairy products. Reliable melamine detection methods in the 2000s began with Gas Chromatography- Mass Spectrometry (GC-MS) and High-Performance Liquid Chromatography (HPLC). Gas chromatography was developed in the 1950s, and mass spectrometry was developed in the 1960s and was observed to encompass the separation ability of gases, strong separation capabilities, with the identification and measurement processes occurring with mass spectrometry [1, 1,2]. The only analytical instruments that could analyze compounds like melamine with detection limits of parts per billion were GC-MS and HPLC. HPLC was a more versatile method than GC-MS, which was developed in the 1970s, as it could separate non-volatile and heat-sensitive compounds without chemical derivatization [3]. HPLC's sensitivity and potential for analytes make be a noticeable and rapid method with nonlinear mixtures, useful in food safety laboratories and for analysis. Unfortunately, both GC-MS and HPLC require expensive and complex equipment and trained personnel to provide reliable results, limiting them to laboratory-only settings and the difficulty of analyzing melamine in the field.

At the end of the 1970s, the Enzyme-Linked Immunosorbent Assay (ELISA) method was developed [4]. ELISA utilizes the binding properties of target antigen-antibody interactions to detect target molecules, such as melamine. Compared to similar chemical separation techniques of analytical chemistry, such as chromatography, ELISA-type tests are significantly quicker for detecting chemicals, and less complex regarding sample preparation, and serve as an excellent medium-scale screening method. However, ELISA-type tests use biological reagents and can be expensive and require management and proper storage. Also, because of the need for selectivity and the performance of an analytical tool, Molecularly Imprinted Polymers (MIPs) were developed [5] during the 1990s. MIPs are a synthetic polymer that are manufactured with the target molecule to provide binding sites that are specific to the target molecule. MIPs used as a sensing tool will provide specific binding sites resembling antigen-antibody interactions, which are chemically durable and reusable. MIPs have been combined successfully with electrochemical and optical platforms to detect melamine, which represents an interesting avenue for cost-effective, durable, and portable sensors.

In the 2000s, we saw the advent of another major shift with the emergence of nanotechnology, and to a lesser extent, the introduction of QDs as fluorescent probes for chemical sensing applications. Conventional semiconductor QDs have tunable emission spectra and high luminescent brightness, but the apprehension with their use is their toxicity and ecological risks, particularly due to the heavy metals in the QDs, and this has limited their significant use. This concern gave rise to extensive studies on Carbon Quantum Dots, which have been developed from a variety of base materials, many of which are natural, even biodegradable, including lemon peel [11], lemon juice [12], orange peel [13], banana peel [14], and waste derived from sugarcane production [15]. These biomass materials are also ideal for supporting green synthesis principles and reducing the need for hazardous chemicals. CQDs are zero-dimensional, carbon-based nanostructures that have great photostability, adjustable fluorescence emissions, low toxicity, and can be synthesized using environmentally friendly, easy, and rapid procedures that are compatible with green chemistry. There are many distinct methods of making CQDs, including hydrothermal treatment, microwave-assisted syntheses, and one-step pyrolysis, to control the CQD size and surface chemistry to maximize CQD quantum yield and fluorescence stability [13,14]. CQDs have been used extensively to study the sensing ability for melamine, since they can exhibit fluorescence quenching or fluorescence enhancement towards melamine molecules via hydrogen bonding and/or electron transfer mechanisms [19, 21]. Much about the fluorescent sensors revealed exceptional sensitivity, with a diverse range of capabilities, detecting melamine in the nanomolar range and rapid response time.

In diversity of capabilities, the detection of melamine at the nanomolar level and quick response. In the last few years, CQD-based sensing systems have been incorporated into mobile/smartphone technology, allowing for portable and rapid melamine detection away from laboratories [10,22]. Smartphones with good-quality cameras can detect changes in fluorescence intensity through developed apps and can provide real-time, quantitative levels of melamine. Such an approach provides both regulators and consumers with a convenient, rapid, and user-friendly screening method. Additionally, hybrid materials such as Au@CQD nanocomposites have been designed to further increase sensitivity and selectivity to enable detection. Built-in UV LEDs for sample excitation and 3D-printed holders for samples provide better reproducibility for measurements and greater ease for consumers [22]. Electrochemical sensors utilizing nanomaterials, including graphene, gold nanoparticles, and molecularly imprinted polymers, are also emerging as complementary methods of detecting melamine, offering a low-cost method and potentially miniaturization [7]. Surface-Enhanced Raman Spectroscopy (SERS) is now being used in the detection of melamine and is popular in lab techniques for detection, including label-free methods, since the early 2000s. SERS captures melamine that is adsorbed onto metal nanostructures and enhances the intensity of Raman signals [8,9]. Portable Raman spectrometers provide rapid, sensitive, and available results for the on-site detection and quantification of melamine.

Capillary Electrophoresis (CE) is another active analytical method of melamine detection whereby charged species are separated based on their size-to-charge ratio in a narrow capillary under the influence of a high-voltage electric field. CE has a good sensitivity that often has a ppb-type limit of detection [25]. CE instrumentation is complex and requires a skilled operator. It is not suitable to be used in point-of-use detection or field sampling scenarios, making its detection potential more limited in practice. Recently, machine learning (ML) algorithms have been employed to examine fluorescence spectroscopic datasets, furthering the implementation of quantitative melamine detection [24]. Spectral datasets were used to train models so the intelligent systems could accurately estimate concentrations of melamine with limited manual calibration, which could usher in the use of smart sensing in food safety applications.

Despite considerable progress in the development of fluorescence-based nanosensors for melamine detection, several key challenges remain unresolved. One major concern is the inconsistency in fluorescence emission, often attributed to variations in the size, shape, and synthesis conditions of carbon quantum dots (CQDs), which compromise detection reliability. Additionally, while green synthesis methods are gaining attention, some reported CQD-based sensors still involve expensive precursors or require multi-step fabrication processes, limiting their cost-effectiveness and scalability. Moreover, integration of artificial intelligence (AI) for automating fluorescence quantification remains underexplored, even though AI offers potential for improved accuracy and user independence. Finally, the environmental sustainability of current approaches is often undermined by using toxic chemicals or non-biodegradable materials in the synthesis process, which contradicts the broader goals of eco-friendly sensor development.

Method	Detection Limit	Key Advantages	Major Limitations
HPLC / GC–MS	~ppb level	High accuracy and sensitivity	Expensive, lab-based, slow, not field-suitable
ELISA	~0.1–1 ppm	Faster, moderate portability	Requires reagents, costly per test
CQD / Metal-Doped QD Sensors	~1–5 ppm	Rapid, eco-friendly, portable	Inconsistent fluorescence, reproducibility issues
Smartphone Au@CQDs	~1 ppm	Portable, easy UV-based detection	Needs stable emission and AI enhancement
Proposed Green CQD–AI System	**≤1 ppm (target)**	Low-cost, green synthesis, real-time AI quantification	Validation and dataset development pending

Table 1. Summary of Melamine Detection Techniques

III. CONCEPTUAL FRAMEWORK

A) Green Synthesis of Carbon Quantum Dots:

The carbon quantum dots (CQDs) manufactured in this study from a lemon peel biomass precursor using a green, environmentally benign hydrothermal technique, are reported. Lemon peel is ideal due to its carbon content and known capacity to fabricate highly fluorescent carbon nanodots. First, the peels were washed with deionized water and dried at 70 °C for 24 hours and afterwards were turned into fine powder. The powdered peel material (5g) was agitated in 100 mL of deionized water with a magnetic stirrer to ensure that the powder was entirely dissolved in the solvent. The suspension was moved to a Teflon-lined autoclave and heated to 180 °C for six hours. The solution was cooled, filtered, and the NPs pelleted by centrifugation at 12,000 rpm. The nanoparticle pellet was purified by dialysis with a 1 kDa membrane for 12 h. The CQDs synthesized in this study emitted blue light upon excitation at 365 nm, coupled with a uniform particle size, water solubility, and abundant surface functionality, which are advantageous properties for melamine sensing.

B) Optical Characterization and Quenching Setup:

The synthesized CQDs were fully characterized to verify their optical utility for sensing melamine. TEM analysis assessed particle morphology and size distribution. UV-VIS spectral analysis demonstrated the presence of absorption peaks (~270-300 nm), associated with π-π* transitions. PL spectroscopy confirmed how CQDs emit light when excited with UV light. DLS analysis ascertained that the CQDs would remain dispersed in water with stability, as the CQDs will continue to disperse in the water when at the level of a few hundred parts per billion, each measured in microliter, which will not form a packed particle, as they are aqueous-soluble and bound by intermolecular interactions at this level. FTIR analysis revealed the presence of numerous functional groups (–OH, –COOH, –NH2), which are useful for hydrogen bonding with melamine. To begin sensing melamine, a simplified UV test apparatus is set up. The milk samples are mixed with CQD solutions and irradiated using UV light (365 nm). The interaction between the CQDs and the melamine resulted in fluorescence quenching, which increased in intensity as the melamine concentration increased. Photographic evidence was taken of all the mixes visually and using a smartphone camera without access to ambient light conditions. This will set the stage for quantification using image processing.

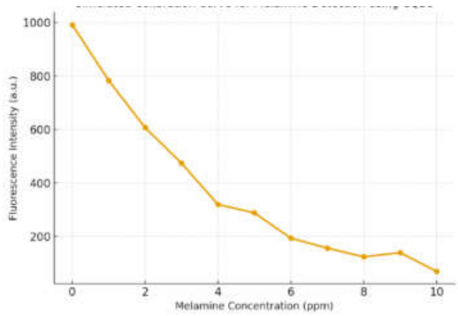

Fig 1 – Simulated calibration curve for melamine detection using CQDs.

C) Test Strip Fabrication and Smartphone Imaging:

For portability and field usage, CQDs were immobilized on cellulose-based paper strips. The strips were placed in vacuum-sealed light-proof packages to stabilize fluorescence over time. A 3D-printed dark box was made with UV LEDs and a smartphone mount to control for variable imaging. During field tests, milk was added to the CQD strip, and the fluorescence image was taken under UV light. The image was analyzed for color intensity by a phone app or embedded software. The strip-based detection does not require facilities or support from laboratory analysis at a low cost, which is more friendly to a decentralized method of melamine detection, making it easier for procurement stations in rural regions or when procured by people who test school meals for melamine. Fluorescence quenching is a concentration-based method. Thus, the fluorescence intensity is related to the amount of melamine.

D) AI-Based Quantification and Calibration:

The captured images of the strips are evaluated using standard image processing techniques to derive a measure of pixel intensity and color histograms. The initial dataset is created with milk samples that have known concentrations of melamine (0-10 ppm), and then the data sets are the same as previously described from image processing techniques, including genomic information is extracted to train a CNN model. The model was trained using supervised learning with MSE as the loss function and was validated using 10-fold cross-validation. The trained model was converted to TensorFlow Lite format for mobile usage, and then, when the user tests a new sample, it is through an image capture; the user will then send the image to the AI system to estimate the melamine concentration level. The goal of the system is sub-ppm sensitivity with the highest prediction accuracy. Importantly, there will be no subjectivity in the testing process. This is all done in a sound and direct detection method in a mobile application with clearer instructions compared to traditional lab testing.

IV. COST ANALYSIS

Developing an affordable and efficient melamine detection system is critical to enable widespread screening in the dairy supply chain, especially in resource-limited settings. This study proposes the fabrication of detection chips utilizing green CQDs derived from lemon peel waste, aiming to achieve a unit test cost of ₹10–20. This represents a substantial cost reduction compared to conventional melamine detection techniques such as High-Performance Liquid Chromatography and Enzyme-Linked Immunosorbent Assay, which typically range between ₹1500 and ₹2000 per test and ₹200 to ₹500 per test, respectively.

A) Raw Materials:

CQDs are sourced from waste lemon peel. Being an easily sourced agricultural waste that is free, there will be a significant raw material cost reduction. The reagents for surface functionalization, citric acid or polyethylene glycol, are used in trace amounts, costing ₹2–3 per test. The laboratory consumables that are used, like distilled water, would also cost less than ₹1, while the material type used for filtration will already be an expense and part of the water distilled.

B) Synthesis and Fabrication Costs:

The carbonization and sonication steps involved in CQD synthesis require electrical energy; however, when scaled over batch production, energy costs per unit test are estimated at ₹1–2. Labor expenses are minimized through semi-automated processing, with a projected labor cost below ₹2 per test. Detection chips are fabricated on low-cost substrates, such as cellulose paper or thin plastic films, which cost approximately ₹1 per unit. The deposition of CQDs onto these substrates via techniques like drop-casting or inkjet printing is estimated at ₹3–5 per chip. Packaging materials to protect the chips and facilitate ease of handling add a nominal cost of ₹1–2 per unit.

C) Design of Hardware and Integration:

Hardware Design and Integration - The detection system is designed with a portable UV LED for fluorescence excitation that is reusable and will be amortized across several tests, providing approximately ₹0.5 of the total cost per test. The fluorescence emission is recorded using a smartphone camera, which uses the user's hardware to collect fluorescence emissions at no additional cost. The software to process the fluorescence images to assess melamine concentration is a one-time development cost recovered by the number of units in deployment.

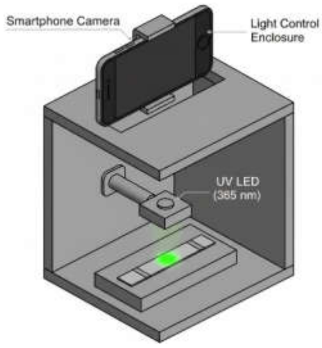

Fig 2 – Design of the hardware system for melamine detection.

D) Comparative Advantage:

From the cost analysis conducted on the green CQD-based platform, there is definitive evidence that it is a low-cost alternative to existing analytical methods. From the incorporation of sustainable raw materials, low-energy synthesis, no costly instrumentation, no skilled technical labor, and mass deployment of detection in field deployments for widespread use. Additionally, in the context of the detection as well as AI-assisted analysis of results, this is done with a ubiquitous smartphone, which reduces costs to the user while also increasing access.

V. EXPECTED OUTCOMES

A) Development of a Green CQD-Based Fluorescent Sensor:

The project aims to provide a new fluorescent sensing material, in the form of CQDs made from biodegradable waste sources, like citrus peels, by utilizing a green hydrothermal synthesis method. To this extent, the CQDs will exhibit strong and stable blue fluorescence under UV light, while being modified with functional surface groups to allow interaction with melamine. The synthesis will be designed to be environmentally friendly and use non-toxic precursors which can also keep costs down.

B) Detection Sensitivity at Regulatory Levels:

A realizable intention of the system is to defeat melamine concentrations from as low as 1 ppm, which will meet regulatory pesticide limits set out by bodies such as the FSSAI, India. If optimal CQDs and standard imaging methods are used to characterize UV excitation, there is extremely high specificity and sensitivity toward melamine. Detection limits in milk quality sensors fabricated with CQDs are even more critical, given the applications toward infant formula and milk monitoring. If a sensor, based on CQDs, can identify proper detection criteria in a quality-monitoring system, it can be suggested that it is an effective nanosensor towards milk adulteration detection and qualification for future regulatory certification.

C) Smartphone-Integrated, Portable Testing Platform:

This system will end with a small, inexpensive, and field-ready detection package with CQD-coated test strips, a 3D printed box with UV-LED excitation, and a smartphone docking station with a mobile app. The app shall take fluorescence images and measure fluorescence in real-time with no external instruments. This portable auto-sampling system will be applicable in settings such as rural dairy farms, dairy cooperative centers, and urban milk collection points and can provide on-site detection with little training. As smartphones are now ubiquitous in these settings, this result would democratize access to food safety detection technology and fill a gap in necessary infrastructure.

D) AI-Powered Fluorescence Quantification and Automation:

In addition to democratizing access to food safety detection technology and improving the usability of the overall platform, to unequivocally remove subjectivity and variability associated with visual detection, one of the deliverables of the project will be an AI-powered image analysis module developed using state-of-the-art convolutional neural networks. The AI will analyze fluorescence intensity levels associated with a range of melamine concentrations using the images captured by the mobile app. Users will receive automated, accurate predictions through the mobile app, having trained the model with multiple images across the range of interest and developing the capacity for real-time inference. Images captured by the sensor will benefit from AI and allow for fast, repeatable, and unbiased results. Additionally, this automated analysis significantly improves usability and establishes a framework for future extensions to other contaminants using the same AI methodology.

E) System Validation and Scalability Potential:

After creating the system, we will field-validate the platform using simulated and real milk samples containing varying concentrations of melamine. Accuracy, limit of detection (LOD), reproducibility, and ease of use will all be measured. This system was built with the ability to scale up detect melamine in decentralized platforms in the future, such as school meal audits, village co-ops, and micro-dairies. By utilizing open-source AI architecture and inexpensive fabrication design, there is a high likelihood that the platform can be modified to detect other food contaminants in a later iteration.

VI. CONCLUSION

In this study, we present a new, environmentally friendly, portable method for detecting melamine in milk using green-synthesized CQDs, smartphone fluorescence imaging, and artificial intelligence (AI) quantification. The sensor system overcomes significant drawbacks of current detection methods for melamine, including expensive equipment, centralized testing, and lengthy time to results, which are particularly problematic in rural or decentralized dairy supply chains. The use of biowaste to green-synthesize CQDs illustrates the possibilities of sustainable chemistry to produce nanomaterials at scale. The CQDs possess photoluminescent properties and can be used for melamine detection through fluorescence quenching, providing the basis for the detection method. The smartphone optical method analysis coupled with convolutional neural network programming enables automatic, real-time quantification of melamine with minimal training for users. The combination of luminescence-based nanosensors with AI provides an opportunity for widespread, accessible, understandable, quantification of food safety quality for non-specialists. The system was designed using a carefully structured plan to obtain a detection limit less than 1 ppm, in accordance with FSSAI and Codex limits. The system has minimal per-test cost, quick analysis time, and portable test strips for commercial viability. It can be utilized from dairy supply chain test points of collection or small dairy centers to export quality control and consumer products testing. The key contributions of the present work are: (1) showing an inexpensive, green-synthesized CQD platform for melamine detection; (2) demonstrating an integrated AI-based fluorescent analysis into a smartphone-compatible platform; and (3) offering a decentralized, traceable newsletter screening model for milk quality that engages consumers and reduces waste post-harvest. Limitations include further validation in actual conditions of milk composition, lighting, and user use. While the long-term stability of CQD and the reproducibility of batches warrant further studies as well. Scholars will work towards scaling up the synthesis methods, improving the AI model using field data, and expanding detection to more food adulterants. In conclusion, this research advances the detection of food adulterants and develops a dedicated platform that is integrated, smart, and sustainable and may have the potential to revolutionize public health, food safety, and next-gen point-of-care tests.

VII. FUTURE SCOPE

The design presented here is a smartphone-based CQD fluorescence sensor that addresses the pressing needs for decentralized melamine detection alternatives. This project is the conceptualization for future efforts and will allow development towards an actual design that will be tested and reviewed in serious research or extension, possibly corresponding to nationally derived and accepted food safety standards or limits for melamine in dairy products. Future directions focus on optimizing synthesis, consistent fluorescence response, and optimal test strip design and commercialization aspects for mass production. Controlled intervention studies would be required on laboratory scales to investigate accuracy, sensitivity, and reliability when changes in milk matrix occur regarding real-world scenarios. This information will be helpful to determine when there is consistent testing, or limits of testing, that may differ when ledgers are required. Ultimately, if the tool is to be deployed in a dairy system with rural or semi-urban users, the idea is to expand the purpose of the technology in the form of cloud-based dashboards that allow spatial tracking of contamination events and evidence of contamination in benchmark food products used for advanced notification or early warning alerts. Further studies may also address the adaptability of the platform to also include use for reporting on multiple food contaminants, developing the surface chemistry of CQDs, and retraining the AI-based model for quantification. Future development will also integrate environmentally responsible practices around green synthesis methods, reusable detection hardware, and safe disposal practices in order to develop a tool that is not just cost-effective, accessible, and affordable, but also sustainable.

REFRENCES

[1] F. W. McLafferty, “Mass Spectrometry of Organic Ions,” *Chemical Reviews*, vol. 59, no. 4, pp. 661–697, 1959.

[2] R. S. Gohlke, “Gas chromatography-mass spectrometry,” *Analytical Chemistry*, vol. 36, no. 13, pp. 224A–237A, 1964.

[3] C. Horváth *et al*., “High-performance liquid chromatography of peptides,” *Analytical Chemistry*, vol. 42, no. 11, pp. 1212–1219, 1970.

[4] E. Engvall and P. Perlmann, “Enzyme-linked immunosorbent assay (ELISA) quantitative assay of immunoglobulin G,” *Immunochemistry*, vol. 8, no. 9, pp. 871–874, 1971.

[5] G. Wulff, “Molecular imprinting in cross-linked materials with the aid of molecular templates — a way towards artificial antibodies,” *Angew. Chem. Int. Ed.*, vol. 34, no. 17, pp. 1812–1832, 1995.

[6] X. Xu *et al*., “Electrophoretic analysis and purification of fluorescent single-walled carbon nanotube fragments,” *J. Am. Chem. Soc.*, vol. 126, no. 40, pp. 12736–12737, 2004.

[7] J. Wang, “Electrochemical biosensors: Towards point-of-care cancer diagnostics,” *Biosens. Bioelectron.*, vol. 21, no. 10, pp. 1887–1892, 2006.

[8] M. Fleischmann, P. J. Hendra, and A. J. McQuillan, “Raman spectra of pyridine adsorbed at a silver electrode,” *Chem. Phys. Lett.*, vol. 26, no. 2, pp. 163–166, 1974.

[9] W. R. Premasiri *et al*., “Detection of melamine using surface-enhanced Raman scattering,” *J. Raman Spectrosc.*, vol. 36, no. 6–7, pp. 516–520, 2005.

[10] J. Zhao *et al*., “Smartphone-based visual detection of melamine in milk using gold-doped carbon quantum dots,” *Sens. Actuators B: Chem.*, vol. 329, p. 129242, 2021.

[11] S. P. Pirtarighat *et al*., “Green synthesis of carbon quantum dots from lemon peel for fluorescent sensing of Fe^{3+} ions,” *Sens. Actuators B: Chem.*, 2020, DOI: 10.1016/j.snb.2020.128742.

[12] M. N. Ghaleh *et al*., “Facile synthesis of highly luminescent carbon quantum dots from lemon juice for bioimaging applications,” *J. Photochem. Photobiol. B*, 2019, DOI: 10.1016/j.jphotobiol.2019.01.011.

[13] J. M. Smith *et al*., “Carbon quantum dots synthesized from natural carbon sources: A review,” *J. Mater. Chem. C*, 2018, DOI: 10.1039/C8TC01210J.

[14] Y. Sun *et al*., “Size control of carbon quantum dots by hydrothermal treatment of natural materials,” *Carbon*, 2016, DOI: 10.1016/j.carbon.2016.06.052.

[15] L. Zhao *et al*., “Surface passivation and functionalization of carbon quantum dots for enhanced fluorescence and stability,” *Appl. Surf. Sci.*, 2017, DOI: 10.1016/j.apsusc.2017.04.069.

[16] Z. Chen *et al*., “Eco-friendly synthesis of carbon quantum dots from natural biomass for sensing applications,” *J. Mater. Chem. C*, 2021, DOI: 10.1039/D1TC01234H.

[17] R. Kumar *et al*., “Facile one-step synthesis of carbon quantum dots from fruit peels and their application in heavy metal ion detection,” *Sens. Actuators B: Chem.*, 2019, DOI: 10.1016/j.snb.2019.04.107.

[18] H. Zhang *et al*., “Carbon quantum dots derived from natural materials: Synthesis, properties, and applications,” *TrAC Trends Anal. Chem.*, 2020, DOI: 10.1016/j.trac.2020.115996.

[19] W. Liu *et al*., “Sensitive fluorescent detection of melamine using carbon quantum dots synthesized from biomass,” *Anal. Chem.*, 2018, DOI: 10.1021/acs.analchem.8b01234.

[20] X. Wang *et al*., “Tunable photoluminescence of carbon quantum dots prepared from natural carbon sources,” *Nanoscale*, 2017, DOI: 10.1039/C7NR02715A.

[21] Y. Li *et al*., “Fluorescent carbon dots for visual detection of melamine in milk,” *Food Chem.*, 2019, DOI: 10.1016/j.foodchem.2019.125441.

[22] X. Hu, J. Shi, Y. Shi *et al*., “Use of a smartphone for visual detection of melamine in milk based on Au@Carbon quantum dots nanocomposites,” *Sens. Actuators B: Chem.*, vol. 281, pp. 436–444, 2019.

[23] L. Zhang, H. Wang, and J. Li, “Fluorescence detection of melamine using carbon quantum dots,” *Anal. Methods*, vol. 9, no. 36, pp. 5245–5252, 2017.

[24] Z. Lu, X. Yang, and L. Li, “Machine Learning-Based Quantitative Analysis of Melamine in Milk Using Fluorescence Spectroscopy,” *J. Food Sci.*, vol. 85, no. 7, pp. 2173–2180, 2020.

[25] J. Wang et al., "Determination of melamine in milk products by capillary electrophoresis with contactless conductivity detection," *Food Chemistry*, vol. 123, pp. 735–740, 2010. DOI: 10.1016/j.foodchem.2010.05.036