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Tobacco-Derived Carbon Dots for salivary miRNA Detection in Early Oral Cancer Diagnosis: A Systematic Review

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Abstract

Introduction: Oral cancer continues to pose a profound global health challenge due to delayed diagnosis and limited screening efficacy. Salivary microRNAs (miRNAs), particularly miR-21, have emerged as non-invasive, specific biomarkers, providing a critical avenue for early-stage detection. To address this, the valorization of tobacco agricultural waste into carbon dots through Facile Hydrothermal Method synthesis presents a sustainable solution for real-time detection of salivary miRNAs.

Purpose: This study aims to investigate tobacco-carbon dots for real-time detection of salivary.

Method: Scientific data was collected through a PRISMA-guided systematic search of PubMed, Scopus, and EBSCO databases (2020–2025) using keywords such as 'tobacco-derived carbon dots', 'salivary miRNA', and 'oral cancer', with study quality evaluated using the OHAT tool.

Discussion: A systematic review was conducted following PRISMA guidelines, sourcing studies from PubMed, Scopus, and EBSCO databases published within the last decade. Study quality was assessed using QUADAS-2 tools. Fourteen studies met the inclusion criteria. The findings suggest that T-CDs hold substantial promise for salivary miRNA sensing in early oral cancer detection while supporting sustainable practices in green dentistry.

Conclusion: Tobacco-carbon dots hold significant potential as an innovative solution for early detection of oral cancer risk, allowing patients to receive prompt treatment before cancer metastasizes

Keywords: Tobacco-carbon dots; MiRNA; Oral Cancer

1. Introduction

Oral squamous cell carcinoma (OSCC) represents a predominant subset of head and neck squamous cell carcinoma (HNSCC) and is recognized as one of the most prevalent malignancies in the head and neck region. Its primary etiology is closely linked to prolonged exposure to carcinogens derived from excessive tobacco and alcohol consumption [13]. OSCC remains a leading cause of mortality among oral cancer patients, a situation frequently exacerbated by delayed diagnosis and the paucity of real-time screening modalities. According to the 2020 GLOBOCAN estimates, OSCC ranks seventh globally in terms of cancer prevalence, accounting for approximately 4.5% of all cancer diagnoses worldwide. Furthermore, it contributes to roughly 450,000 deaths annually, representing 4.6% of total global cancer fatalities [17]. Globally, OSCC exhibits a higher incidence in males than females, with a 2:1 ratio, and is most commonly diagnosed in individuals over the age of 50. The highest incidence rates are recorded in South and Southeast Asia [18]. The global incidence of OSCC is also trending upward across various nations, particularly among younger populations, with a

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predicted annual incidence increase of 30% by the year 2030. This surge is largely attributed to shifting lifestyles, including increased alcohol and tobacco use in developing countries [13,19]. In Indonesia, the number of new oral cancer cases reached 5,078 in 2018, with a mortality count of 2,326 [16].

Despite its high prevalence, the early diagnosis of OSCC remains a formidable challenge in clinical practice. The majority of OSCC cases are diagnosed at advanced stages, which directly diminishes patient survival rates; thus, early detection is of paramount importance. Conventional diagnostic protocols necessitate tissue biopsy, which while still regarded as the gold standard, is inherently invasive, requires extensive histopathological processing time, is often costly, and can lead to fatal diagnostic delays [14,20]. Additionally, tumor heterogeneity and potential sampling bias increase the risk of misdiagnosis or the failure to capture malignant lesions in their early phases.

One of the critical challenges in advancing diagnostic technology is the development of detection systems that are not only sensitive and specific but also accessible, rapid, and environmentally sustainable. In the context of molecular detection, particularly microRNAs such as miR-21, which has been consistently proven to be overexpressed in OSCC, there is an urgent need for detection platforms capable of operating in a real-time and non-invasive manner [3,5,11].

Carbon dots (CDs), which are nano-sized carbon particles characterized by high photoluminescence, low toxicity, biocompatibility, high stability, and ease of synthesis, have emerged as a promising solution in the development of optical biosensors [6,8]. Due to their ability to be conjugated with DNA probes and emit measurable fluorescence, CDs are ideal for detecting small biomolecules such as miRNAs, including miR-21 [1,9,10]. This technology facilitates accurate and rapid analysis based on fluorescence ratio shifts, potentially enabling saliva-based cancer screening without the need for complex laboratory infrastructure [1].

Remarkably, CDs do not necessarily require expensive or synthetic precursor materials. In a more sustainable approach, agricultural waste such as tobacco leaves can be processed into tobacco-derived carbon dots (T-CDs) through a facile hydrothermal synthesis method. Tobacco is selected not only for its abundant availability but also for its high organic carbon content and its ability to produce stable fluorescence emissions [4]. By utilizing tobacco waste, this approach not only adds value to previously discarded materials but also supports the principles of green dentistry an environmentally conscious and sustainability-oriented dental practice.

The implementation of tobacco-derived carbon dots (T-CDs) in biosensor systems for miR-21 detection offers more than just diagnostic accuracy and efficiency for OSCC; it represents the integration of technological innovation and ecological stewardship. This approach aligns with the United Nations Sustainable Development Goals, particularly SDG 3 (Good Health and Well-being) and SDG 12 (Responsible Consumption and Production), by promoting the application of eco-friendly diagnostic technologies capable of enhancing healthcare quality while minimizing the environmental footprint of medical practices. Therefore, T-CDs serve as a relevant and prospective solution for the future of sustainability-based early diagnosis of oral cancer.

2. Method

This study was conducted following the PRISMA guidelines to evaluate the diagnostic efficacy, molecular mechanisms, and green synthesis of tobacco-derived carbon dots (T-CDs) for salivary miRNA detection in oral cancer. A comprehensive search was performed until April 28, 2025, across PubMed, Scopus, and EBSCO databases using a specialized Boolean strategy: ("Carbon Dots" OR "Carbon Quantum Dots" OR "CQDs" OR "Carbon Nanodots") AND ("Tobacco-Derived" OR "Tobacco Waste" OR "Tobacco Biomass") AND ("miRNA" OR "microRNA" OR "Salivary miRNA" OR "Salivary microRNA" OR "miR-21") AND ("Oral Cancer" OR "OSCC" OR "Oral Squamous Cell Carcinoma") AND ("Diagnosis" OR "Detection" OR "Biomarker" OR "Early Detection") AND ("Fluorescence" OR "Dual-Emission" OR "Ratiometric Sensing" OR "Biosensor") AND ("Green Synthesis" OR "Facile Hydrothermal Synthesis" OR "Eco-Friendly Synthesis") AND ("Sensitivity" OR "Specificity" OR "Accuracy" OR "Limit of Detection"). Based on the PICO framework, inclusion criteria encompassed peer-reviewed original English research (2020–2025) involving T-CDs for in vitro or in vivo oral cancer diagnostics, while articles with full-text restrictions or insufficient data were excluded. Data extraction was performed independently by three reviewers to ensure consistency across parameters including study design, population, intervention, and primary outcomes. The study employed a descriptive quantitative analysis, and the risk of bias for all included literature was rigorously assessed using the Office of Health Assessment and Translation (OHAT) tool to ensure scientific validity.

3. Result

Table 1 Results of the literature review on the

Authors	Title	Result	Conclusion
Viviana Bressi, Alina M. Balu, Daniela Iannazzo, and Claudia Espro	Recent advances in the synthesis of carbon dots from renewable biomass by high-efficient hydrothermal and microwave green approaches	The green synthesis of carbon dots (CDs) from renewable biomass via hydrothermal and microwave methods is considered highly effective due to its efficiency, environmental friendliness, cost-effectiveness, scalability, solvent-free nature, and utilization of abundant biomass resources.	Hydrothermal carbonization (HTC) and microwave-assisted methods are the most suitable technologies for converting abundant biomass waste into carbon dots, offering high efficiency, high yield, low energy consumption, and significantly reduced reaction time compared to conventional heating.
Catarina S. M. Martins, Alec P. LaGrow, and Joao A. V. Prior˜	Quantum Dots For Cancer-Related miRNA Monitoring	The application of quantum dots as biosensors for cancer-related microRNA detection encompasses synthesis methods, surface modification, and functionalization with nucleic acids. While various approaches have demonstrated significant potential for cancer screening, further validation is required before they can be implemented in clinical settings.	MiRNAs are key biomarkers for early cancer detection, and quantum dot–based sensing platforms offer advantages over conventional methods due to their optoelectronic properties, cost efficiency, and simplicity. However, broader clinical application requires a shift from proof of concept studies to clinical validation, along with standardized reporting of quantum yield, stability, and morphology to support reliable comparison and clinical integration.
Hui Yang, Yunlong Wei, Xiufang Yan, Chao Nie, Zhenchun Sun, Likai Hao, and Xiankun Su	High-Efficiency Utilization of Waste Tobacco Stems to Synthesize Novel Biomass-Based Carbon Dots for Precise Detection of Tetracycline Antibiotic Residues	The one-pot hydrothermal method successfully synthesized carbon dots from waste tobacco stems for the sensitive and selective detection of the tetracycline antibiotic via the inner filter effect mechanism, with a limit of detection as low as 1.328 nM and a linear range up to 200 μM	Waste tobacco stems were converted into stable yellow-green fluorescent carbon dots via a one-pot hydrothermal method, demonstrating pH responsiveness and high sensitivity for tetracycline detection through an inner filter effect mechanism, with nanomolar detection limits, supporting their application as a sustainable and label-free sensor for environmental water monitoring.
Yasamin Ghahramani, Seyedeh Sara Tabibi , Mohammad Mizanur Rahman Khan, Alireza Asadi, Elaheh Mohammadi, Ehsan Khaksarf, Erfan	Recent advances in bioactive materials: Future perspectives	The advancement of nanotechnology drives the development of innovative biosensors for non-invasive oral cancer diagnosis through saliva analysis. The integration of nanomaterials allows for real-	Nanomaterial-based biosensors enable sensitive, non-invasive detection of oral cancer biomarkers through electrochemical and optical mechanisms, supporting rapid point-of-care diagnostics, but

Khaksarf, Masoomeh Yari Kalashgrani, Mohammed M. Rahman, Wei-Hung Chiang, Seyyed Mojtaba Mousavi	and opportunities in oral cancer biosensing	time biomarker monitoring, increasing diagnostic accuracy, early intervention, and personalized therapy.	their clinical translation is limited by challenges in large-scale fabrication, reproducibility, and regulatory approval.
Somayeh Mohammadi, Abdollah Salimi, Zohreh Hoseinkhani, Foad Ghasemi, and Kamran Mansouri	Carbon dots hybrid for dual fluorescent detection of microRNA-21 integrated bioimaging of MCF-7 using a microfluidic platform	A dual-emission fluorescent sensor based on carbon dots was developed for ratiometric detection of microRNA-21 and bioimaging in a microfluidic device. The sensor showed satisfactory recovery rates in human serum samples and a detection limit down to 3 cells in 10 μL on the MCF-7 cell line. This microfluidic system is effective for bioimaging, showing potential application in the clinical diagnosis of microRNA-related diseases.	A ratiometric fluorescence assay based on ΔF540/ΔF410 using dual-emissive carbon dots enabled attomolar-sensitive microRNA-21 detection with high specificity, effective cellular imaging, and reliable performance in clinical serum samples, supporting its potential as a scalable diagnostic platform for clinical oncology.
Zhenzhen Wang, Yiping Chen, Menghan Zhang a , Linlin Xu , Yichun Xu, Li Chen, Xinyang Yin, Shuangying Yang, Shaohuang Weng , Yanjie Zheng , Jianyong Huang	Fluorine-doped carbon dots (F-CDs) adsorbing DNA via hydrophobic interaction play dual-role of quenching carrier and signal reference for ratiometric fluorescence strategy to detect microRNA	Fluorine-doped carbon dots (F-CDs) were synthesized and showed interaction with single-stranded DNA (ssDNA) through hydrophobic interaction, causing quenching of the dye-labeled ssDNA without disturbing the fluorescence stability of the F-CDs themselves. This F-CDs-based method has high sensitivity and reproducibility in detecting let-7a, with a linear range of 1.0	Amphiphilic negatively charged green fluorescent F-CDs were synthesized via a simple hydrothermal method and shown to adsorb ssDNA predominantly through hydrophobic interactions while maintaining stable inherent fluorescence and strong quenching of dye-labeled ssDNA. This ratiometric fluorescence system enabled robust, interference-resistant, and accurate let-7a detection, demonstrating strong potential for rapid miRNA diagnostics in clinical applications.
Min Yang, Yujia Yan, Fengqin He, Zijian Wang, Enzhou Liu, Jun Fan d	Green synthesis of fluorescent carbon dots from discarded cigarette butts as an effective fluorescence probe for sensing iron ions	The green synthesis method was developed to produce fluorescent carbon dots (CDs) from discarded cigarette butts to detect iron ions (Fe^{3+}) with high selectivity and sensitivity. Testing on tap water samples showed satisfactory results, confirming its reliability for real-world applications. This method has a limit of detection of 0.2 μM and high specificity towards Fe^{3+} with minimal interference from other metal ions.	In summary, a new fluorescent probe was designed for the sensitive and selective determination of Fe3+ based on CDs obtained from discarded cigarette butts. And, the designed fluorescent probe was applied to the determination of Fe3+ in the tap water samples with satisfactory results obtained, which further promoted the development of CDs in the fields of molecular detection.
Zhuoling Zhong, Xingying Lia, Shuyao Liua, Chuanwei Zhanga,	In vivo study of a novel, safe, rapid, and	FA-DCCDs have good biocompatibility and are nearly non-toxic. These nanoparticles show high selectivity and are	Dual-emissive carbon dots synthesized from low-toxicity precursors exhibited red emission at λem = 620 nm with

Xiaoping Xu, and Liyun Liao	targeted red carbon dot probe for recognition of tumors with high expression of folate enzyme	more easily absorbed by tumor cells with high folate receptor expression, making them effective for targeted imaging of tumors with folate receptor overexpression.	high tissue penetration, while folic acid functionalization shifted the emission to 560 nm and significantly enhanced targeting specificity, cellular uptake, and tumor selectivity, supporting their potential as high quantum yield probes for biological imaging and future clinical cancer diagnostics.
Chunyu Zhou, Jialing Du, Hanqing Zhao, Zhili Xiong, Longshan Zhao	Green synthetic carbon quantum dots based on waste tobacco leaves and its application to detecting borax content in flour and its products	This study developed a fluorescence probe based on carbon quantum dots (CQDs) for detecting borax in food samples, showing a linear relationship with borax concentration. The method was successfully applied to real food samples such as flour, bread, and instant noodles with satisfactory recovery rates, and offers advantages in terms of cost, simplicity, and efficiency compared to other detection methods.	Discarded tobacco leaves were used for the first time to synthesize CQDs via an environmentally friendly hydrothermal method, yielding fluorescent probes capable of sensitive and selective borax detection, with successful validation in real samples.
Boye Zhang, Qianqian Duan, Haichao Zhao, Yixia Zhang, Xiaoning Li, Yanfeng Xi, Zhifang Wu, Li Guo, Pengcui Li, Shengbo Sang	Application of carbon dots in nucleolus imaging to distinguish cancerous cells from normal cells	m-CDs have high photostability, good cell uptake efficiency, low toxicity, and good compatibility as a counterstain, making them suitable for biological imaging. Their high affinity for nucleolus RNA allows for accurate visualization of the nucleolus to differentiate between cancerous and normal cells. Furthermore, m-CDs can monitor nucleolus dynamics during doxorubicin-induced apoptosis, making them a potential tool for real-time monitoring of cell apoptosis and evaluation of drug effectiveness	A nucleolus-specific probe based on m-CDs was developed, exhibiting ultra-small size, high photostability, efficient cellular uptake, low cytotoxicity, and stable nucleolar imaging across multiple cell types, enabling cancer cell discrimination, real-time monitoring of nucleolar dynamics during apoptosis, and evaluation of drug efficacy for biomedical applications.
Lu-Shuang Li, Xiao-Hao Chen, Yu Pei, Xiao-Lin Xi, Cong-Ting Wu, Shuang Cai, Jing Li, Wei Gong	A label-free fluorescence aptasensor for salivary exosomes based on a nano-micro dual-scale signal amplification strategy	A label-free aptasensor was developed for the sensitive detection of salivary exosomes via a "one exosome to many carbon dots" signal conversion with nano-micro amplification. With a linear range of $2{,}5 \times 10^2$–5×10^8 particles/mL and a LOD of 100 particles/mL, this device has the potential for oral cancer screening by differentiating exosome levels in OSCC patients and healthy individuals	A label-free aptasensor employing a one-exosome-to-multiple–carbon-dot signal conversion and dual-scale signal amplification was developed, demonstrating low detection limits, good anti-interference performance, and effective discrimination between OSCC patients and healthy individuals, supporting its potential for noninvasive cancer screening and multi-tumor diagnostics.
Kiran B. Jadhav, MDS, Vandana Shah, MDS, Nirali Chauhan, MS,	Expression of microRNA-21 in saliva and	Sensitivity 82.4%, specificity 80.6% for miR-21-3p tumor tissue; saliva accuracy 65–71.5%	MiR-21 serves as a definitive biomarker for OSCC metastasis, with tumor tissue expression showing strong correlation with

ENT, Naveen Shah, MDS, and Ghanshyam Parmar, M Pharm, PhD	tumor tissue of patients with OSCC: A predictor of cervical lymph node metastasis		histopathology and higher sensitivity and specificity than saliva analysis and radioimaging for pretherapeutic lymph node assessment.
Aarushi Garg, Aadithya B. Urs, Bidhan Chandra Koner, Jeyaseelan Augustine, Sameer Ahmad Guru	Evaluation of Diagnostic Significance of Salivary miRNA-184 and miRNA-21 in OSCC and OPMD.	miRNA-21 is elevated in OSCC & OPMD ($p<0.001$); AUC 0.80, sensitivity 80%, specificity 70% for OSCC.	Salivary miRNA-21 and miRNA-184 may be beneficial for the early detection of OSCC and OPMD. Also, saliva can be used for detecting neoplastic transformation of oral mucosa since it is non-invasive and easily accessible.
Zhenzhen Wang, Zhiqiang Xue, Xiaoli Hao, Chenfang Miao, Jianzhong Zhang, Yanjie Zheng, Zongfu Zheng, Xinhua Lin, Shaohuang Weng	Ratiometric fluorescence sensor based on carbon dots as internal reference signal and T7 exonuclease-assisted signal amplification strategy for microRNA-21 detection	LOD: 1 pM; Linearity 0.05–10 nM (R^2=0.998); results consistent with qRT-PCR; high accuracy, selective towards miR-21, and resistant to protein interference	A simple and rapid ratiometric fluorescence sensor combining carbon dots and T7 exonuclease amplification enabled reproducible and specific miRNA-21 detection, with single-base mismatch discrimination and clinical blood sample results consistent with qRT-PCR, supporting its potential for reliable clinical bioanalysis.
Wei Liu,, Huan Shi, Zengtong Zhou, Chenping Zhang, Xuemin Shen	Association of salivary miRNAs with onset and progression of oral potentially malignant disorders: Searching for noninvasive biomarkers	miR-21 and miR-31 are proven to be upregulated in OPMD → OSCC; AUC for miR-31 = 0.789 (sensitivity 87.51%, specificity 73.73%); miR-21 is also significant in 5 large studies.	In summary, aberrant salivary miRNAs, especially miR-21 and miR-31, were associated with onset and progression of OPMD, and could then serve as noninvasive biomarkers for screening OPMD and detecting malignant changes. However, multiple combined markers should be discovered and developed, and large-scale longitudinal study design should be launched to commit surveys acquiring the extraordinary disease prediction.

4. Discussion

Tobacco, a plant traditionally synonymous with health risks, is currently undergoing a paradigm shift in meaning through the lens of eco friendly technology. Within the framework of green dentistry, agricultural tobacco waste is repurposed as an innovative foundation for molecular diagnostics. Plant residues such as dried leaves and tobacco stalks contain a high concentration of polycyclic aromatic carbon structures, making them an ideal carbon source for

the synthesis of carbon dots (CDs), highly fluorescent nanoparticles utilized in precision biomolecular detection. Through a facile hydrothermal synthesis approach, dried tobacco leaves are transformed into tobacco derived carbon dots (T CDs), nano sized carbon particles with superior fluorescent capabilities. In this synthesis process, 2 grams of dried and finely ground tobacco leaves are mixed with 1.25 mL of ethylenediamine as a nitrogen donor. This mixture is dissolved in ultrapure water and sonicated for 30 minutes at room temperature to ensure homogeneity. Subsequently, the reaction solution is placed into a Teflon lined stainless steel autoclave reactor and heated at 220 degrees Celsius for 12 hours, facilitating the thermal transformation of tobacco biomass into carbon nanodots [4].

Following the heating process, the solution is naturally cooled and centrifuged at 4000 rpm for 15 minutes to isolate larger fractions. The resulting filtrate is filtered through a 0.22 micrometer membrane to ensure only nano sized particles remain, yielding a T CD solution ready for use and storage at 4 degrees Celsius. Further characterization using transmission electron microscopy reveals that T CD particles are spherical with an average size of approximately 6.3 nm, displaying a crystalline graphite structure with a lattice spacing of about 0.2 nm. Meanwhile, Fourier transform infrared spectroscopy and X ray photoelectron spectroscopy analyses confirm the presence of functional groups such as hydroxyl, carboxyl, carbonyl, and amine, which are critical for the conjugation process with biomolecules such as DNA probes [4].

Interestingly, despite originating from a single source, the reaction products exhibit significant optical diversity. Variations in particle size, surface oxidation levels, and crystallinity result in two primary products, namely blue emitting T CDs with fluorescence at 409 nm and yellow emitting T CDs at 543 nm. This divergence arises from reaction conditions that create a particle size distribution spectrum, where smaller oxidized particles emit blue fluorescence, while larger reduced particles emit yellow fluorescence. These fractions are separated using chromatography or filtration techniques before being used synergistically in a dual emission detection system [4,9].

A promising application of T CDs is in biosensor systems for the early stage detection of oral squamous cell carcinoma through the identification of salivary microRNA biomarkers, particularly miR 21. MiR 21 is a short non coding RNA of approximately 22 nucleotides that regulates various tumor suppressor genes and signaling pathways including PTEN, PDCD4, TGF beta, and PI3K AKT [11]. Its consistent overexpression from the early stages of oral squamous cell carcinoma and its presence in saliva make it an ideal candidate for real time and non invasive screening [3,12].

In the developed detection system, blue emitting carbon dots are functionalized with antisense DNA probes specific to the miR 21 sequence. This is achieved by activating carboxyl groups on the carbon dot surface using EDC and NHS coupling agents, enabling covalent bonding with the amine terminated DNA probe. Blue and yellow emitting carbon dots are then combined and excited simultaneously at 360 nm. In the presence of miR 21 in saliva samples, hybridization with the DNA probe induces an inner filter effect, resulting in decreased blue fluorescence while the yellow fluorescence remains stable as an internal reference. Consequently, the fluorescence ratio ΔF543 divided by ΔF409 increases linearly with the logarithmic concentration of miR 21, showing a high correlation coefficient of 0.992 and enabling accurate quantification in complex biological matrices [9,12].

The superiority of this system lies in its sensitivity and selectivity. The platform achieves a detection limit of 50 attomolar, corresponding to approximately three target molecules in 10 microliters of saliva [9]. Moreover, the system is capable of distinguishing miR 21 from homologous microRNAs differing by only a single nucleotide, a major limitation in conventional detection approaches [10]. Signal stability remains unaffected by pH, temperature, or excitation variability, confirming the robustness of the dual emission ratiometric T CD platform.

The implementation of this system is further strengthened through integration with artificial intelligence and machine learning techniques. These approaches automate signal classification, suppress noise, and resolve complex spectral overlaps. Li et al. demonstrated that inverse molecular sentinel strategies combined with surface enhanced Raman spectroscopy enable accurate microRNA detection without amplification in complex biological samples [7]. To analyze multiplexed microRNA signals, algorithms such as convolutional neural networks, extreme gradient boosting, and support vector regression are employed to manage spectral interference and biological variability [7].

Convolutional neural networks extract key spectral features and directly map fluorescence signals to microRNA concentration predictions, achieving low root mean square error values even under low signal to noise conditions. Extreme gradient boosting enhances classification accuracy in non linear spectral patterns, while support vector regression provides precise numerical concentration prediction despite biological outliers [7]. These findings directly support the dual emission T CD detection system, where the ΔF543 divided by ΔF409 ratio serves as a reliable quantitative indicator of miR 21 expression. Artificial intelligence integration enables real time interpretation of fluorescence patterns and discrimination between true biological signals and optical interference in saliva.

Overall, tobacco derived carbon dots synthesized from agricultural waste offer a precise and sensitive diagnostic platform rooted in sustainability principles. By integrating green nanotechnology with artificial intelligence, this approach establishes a non invasive, cost effective, and scalable strategy for early oral cancer detection, aligning technological innovation with environmental responsibility and future clinical implementation.

5. Conclusion

Tobacco-derived carbon dots (T-CDs) demonstrate significant potential as an innovative solution for the early detection of oral cancer, specifically Oral Squamous Cell Carcinoma (OSCC). This platform enables timely intervention and accurate prognosis before the occurrence of metastasis, thereby improving patient survival rates.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that there is no conflict of interest.

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